Proceedings of the second conference

« Sustainable Energy for Africa », (SE4A 2021)

Palais des congrès, Cotonou November 8-11, 2021

Editors: Rajaâ Cherkaoui, Norbert Hounkonnou, Marc Lobelle, Bernard Mairy

SE4A.AFRICA Publishing

ISBN:978-99982-1-881-9

FOREWORD

This conference was organized jointly by the **« Royal Academy of Oversea Sciences » (RAOS)** of Belgium and the **« Académie Nationale des Sciences, Arts et Lettres du Bénin »** (ANSALB) in mixed mode, with authors and participants either present in person in Cotonou or connected via zoom.

A first conference « Sustainable Energy for Africa » had been organized by RAOS in Brussels (23-25 October 2017, Palace of the Academies.

The conference was organized in mixed mode, authors and other participants could be present in person in Cotonou or via zoom.

Authors were allowed to submit either a full text or an abstract to publish in the proceedings.

This book includes the following parts

- Foreword
- Table of contents
- Preface
- The full text contributions
- The abstracts of contributions without full text in these procedings
- The final report of the conference
- Acknowledgements

Preface

The second edition of the international conference "Sustainable Energy for Africa" (SE4A 2021) took place in Cotonou, Benin, from Monday 8 to Thursday 11 November 2021. It was jointly organized by the Royal Academy of Overseas Sciences of Belgium (RAOS) and the Benin National Academy of Sciences, Arts and Letters (ANSALB). The four-day conference gathered together a large number of scientific, technological and political experts from Africa and the World, from the public and private sectors, who are interested in energy and climate issues in Africa.

Indeed, the energy landscape in Africa is changing with significant implications and potential opportunities. It is therefore urgent to advocate for a better exploitation of resources taking into account the major advantages of each energy source. By 2050, Africa, like other continents, will have to face the consequences of greenhouse gas (GHG) emissions, as well as rising temperatures. But it is clear that no one could deny that energy resources are of decisive importance for prosperity and economic development.

To discuss such a theme on sustainable energy in Africa, it was proved to be necessary to address several themes and aspects. The appropriation of renewable energy technologies and the need for the use of secure, competitive and affordable energy systems are the first aspects discussed at this conference in order to show the relationship between energy access and socio-economic development. The energy value chain is also considered. It includes managing energy-based services in an inclusive and sustainable way, optimizing energy-based services for large consumers, and the energy supply chain for all types of consumers. Finally, all aspects of research, innovation and education related to energy-intensive sectors are important. New energy technologies are becoming increasingly appreciated, raising awareness of the transition to cleaner solutions. Enhancement of capacity building through multidisciplinary training and research ensures indeed the availability of human resources with suitable expertise.

We do hope that the various papers and presentations gathered in these proceedings will be useful for further discussions on the best energy solutions for Africa. We express our gratitude to all participants in this second edition of the international conference "Sustainable Energy for Africa" (SE4A 2021) as well as to all those who contributed in one way or another to its success. May the next edition be even more enriching to support further the balanced and inclusive development of the continent!

The Editors
Rajaâ Cherkaoui El Moursli, Norbert Hounkonnou, Marc Lobelle, Bernard Mairy

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FULL PAPERS

Les enjeux de la transition vers un mix énergétique responsable au Bénin

ZANNOU Arnaud
Superviseur Pôle Développement Durable et Energies Renouvelables
Bureau Analyse et Investigation (BAI)
Présidence de la République, Cotonou, Bénin
azannou@présidence.bj

lASSAN Todémane
Directeur Général des Ressources Energétiques (DGRE)
Ministère de l'Energie
Cotonou, Bénin

ASSOUMA Faridath
Experte Energies Renouvelables et Efficacité Energétique (Consultante Technique RECASEB)
Agence Béninoise d'Electrification Rurale et de Maîtrise d'Energie (ABERME)
Cotonou, Bénin

AGBAKOU Vivien
Chargé d'Etudes Energies Renouvelables
Bureau Analyse et Investigation (BAI)
Présidence de la République
Cotonou, Bénin

***Résumé*—Au Bénin, les actions ou investissements stratégiques déjà en cours ou prévus d'ici 2025 se focalisent essentiellement sur les énergies renouvelables (EnR) et la maîtrise d'énergie, et concernent : i) 6 à 7 centrales solaires photovoltaïques cumulant 100 MW ; ii) un barrage hydroélectrique multifonctions de 128 MW ; iii) la prise en compte des énergies renouvelables et de l'efficacité énergétique (EffEn) dans le cadre des infrastructures publiques, dans les secteurs industriel/ménage et pour les centres sociocommunautaires ; iv) la normalisation et la promotion des foyers améliorés et des énergies de cuisson propre ; et v) les mesures et réformes réglementaires (code de l'électricité, électrification hors réseau et normes de performance énergétique), institutionnelles, économiques, fiscales et tarifaires pour attirer les investissements et financements privés.**

Concrètement, on enregistre déjà plusieurs projets d'EnR en cours : subvention de plus de 30 milliards FCFA au profit de 4 centrales d'énergie solaire photovoltaïques ongrid (IPP[1]), de 16 projets d'entreprises privées et 15 organisations de la société civile pour des solutions d'énergie propre hors réseau, construction de la centrale solaire de 25MWc d'Illoulofin extensible à 50 MW (Pobè) etc... Autant d'actions qui constituent des opportunités d'emplois pour la jeunesse, qui doit s'impliquer davantage pour l'accès de tous à des services énergétiques fiables, durables et modernes, à un meilleur coût.

Cependant le développement du capital humain et des compétences du secteur, la recherche-développement et l'innovation ainsi que la connaissance approfondie du potentiel national d'EnR requièrent davantage d'efforts du Gouvernement et de ses partenaires.

Mots clés—transition énergétique, énergie renouvelable, électricité, efficacité énergétique, potentiel énergétique

I. INTRODUCTION

En 2020, la situation énergétique du Bénin est caractérisée entre autres par un faible niveau de développement des énergies renouvelables (EnR) dont la part est estimée à 7,5% dans l'approvisionnement électrique, une prédominance de la biomasse énergie (bois-énergie qui représente 62% des approvisionnements nets d'énergie), et un taux de dépendance de l'étranger en énergie électrique d'environ 35% (en baisse de 41% depuis 2015). Face à cette réalité, le Gouvernement du Bénin dans son Programme d'Actions (PAG 2016-2021 intitulé « Bénin Révélé ») a fait le choix stratégique de développer les énergies renouvelables (hydroélectricité, énergie solaire, biomasse-combustible) et de maîtriser des consommations énergétiques des secteurs d'activité (industriels, tertiaire, bâtiments administratifs, ménages).

L'action du Gouvernement béninois vise à réaliser une transition vers un mix énergétique « responsable » compatible avec ses besoins de développement et ses engagements internationaux, en faisant des énergies renouvelables et de l'efficacité énergétique, la base d'une satisfaction durable et à moindre coût des besoins énergétiques nationaux. La PONAME[2] [1] et la PONADER[3] [2] récemment adoptées, constitueront les principaux leviers de cette transition énergétique. Pour y arriver, il y a lieu de promouvoir la technologie ou forme d'EnR la plus adaptée à chaque besoin, d'attirer les investissements privés, d'imposer les normes et règlements adéquats d'Efficacité Energétique, et d'instaurer une solidarité nationale favorisant l'accès des plus démunis aux services énergétiques efficaces.

Hydroélectricité, Solaire, Biomasse et efficacité énergétique sont perçus comme le socle de la construction énergétique durable en cours au Bénin. Selon les statistiques nationales de 2020 [3], le taux d'accès à l'électricité est de 64,96% en milieu urbain contre 10,35% en milieu rural. L'électricité reste donc inaccessible à une large partie de la population surtout dans les zones péri-urbaines et rurales. La situation énergétique est caractérisée entre autres par un faible niveau de développement des énergies renouvelables dont la part est estimée à 7,48% dans l'approvisionnement électrique, une prédominance de la biomasse énergie de

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1 Producteur Indépendant d'Electricité

2 Politique Nationale de Maîtrise d'Energie

3 Politique Nationale de Développement des Energies Renouvelables

62% et un taux d'autosuffisance en énergie électrique de 64,92% avec un accroissement 2016-2020 de 32,99% (ME/GRE, 2021a).

Le passage à un mix énergétique responsable est aujourd'hui l'opportunité de structurer des filières économiques locales, d'alléger la morosité des secteurs de la santé et de l'éducation et de dissoudre les disparités sociales, toutes dépendantes de l'énergie, dès lors que des projets émergent. C'est l'opportunité de se détacher progressivement des énergies fossiles, polluantes et d'engager un nouveau mode de développement durable respectueux de la nature.

Le cadre politique et stratégique national, mis en place, dès 2020, traduit la vision et les ambitions du Gouvernement de faire à terme, « des énergies renouvelables, la source prioritaire d'une satisfaction durable et optimale des besoins énergétiques nationaux » et « de la maîtrise d'énergie, le garant de la réduction considérable de la consommation, de la dépendance et des dépenses énergétiques sans préjudice de la qualité des services énergétiques ». La PONAME [1] et la PONADER [2] ont été adoptées dans cette dynamique, conformément à l'ODD 7 « Garantir l'accès de tous à des services énergétiques fiables, durables et modernes, à un coût abordable ». De plus, le cadre juridique et réglementaire rendu favorable, le renforcement du cadre institutionnel par la création d'une nouvelle société béninoise de production d'électricité pour porter les grands projets notamment d'énergies renouvelables, la forte implication du secteur privé et de la société civile, la disponibilité des ressources énergétiques renouvelables, et la disponibilité de cycles complets de formation en énergie de l'enseignement secondaire technique à l'enseignement supérieur constituent le socle de cette transition énergétique, désormais en cours au Bénin.

Pour atteindre les objectifs ambitieux d'autonomie énergétique, il faudra consolider et diversifier les ressources énergétiques, améliorer l'accès à l'énergie en quantité et en qualité pour tous et accentuer le renforcement des compétences de tous les acteurs du secteur.

II. TRANSITION ÉNERGÉTIQUE AU BÉNIN

La transition énergétique est devenue un sujet politique important dans le monde et dans la sous-région à travers un certain nombre d'enjeux et de défis qui se posent. En effet, faire la transition énergétique s'appréhende au-delà de la construction des centrales solaires ou de la valorisation de la biomasse-énergie. Cela touche des problèmes aussi divers que l'accès à l'énergie, la croissance économique, l'adéquation entre la production et la consommation, le prix et le coût de la production énergétique, l'impact écologique, l'évolution et l'équilibre du mix énergétique. Nous sommes ainsi enjoints de trouver de nouveaux modes de vie et de développement.

Dans ce contexte, la nécessité de réduire nos besoins en énergie, d'une part, et de trouver de nouvelles sources d'énergie, d'autre part, s'impose. A cet effet, le Gouvernement du Bénin a rendu effectif son élan dès 2016 par deux choix stratégiques : le développement des énergies renouvelables par le solaire PV à hauteur de 95 MW, l'hydroélectricité à travers 2 barrages Dogo-bis (128 MW) et Adjarala (147 MW), et en investissant dans la Filière biomasse-combustible à hauteur de 15 MW [4]. En outre, dans la maîtrise des consommations énergétiques, l'action est portée sur la réduction du besoin en puissance de 80 MW à la pointe, la formulation des normes contraignantes pour réduire les consommations énergétiques, l'implication dans l'éclairage public solaire et le remplacement des lampes incandescentes par les LED tout en accentuant l'efficacité énergétique dans les ménages. Parmi les textes dédiés à ce renouveau, figurent : le décret n° 2018-563 du 19 Décembre 2018 fixant les normes minimales de performance énergétique et un système d'étiquetage des lampes et climatiseurs individuels en République du Bénin et le décret n° 2018 - 415 du 12 septembre 2018 portant règlement de l'électrification hors réseaux en République du Bénin. L'analyse de ces deux décrets révèle la pertinence d'orienter nos réflexions non seulement sur la recherche du potentiel d'énergies renouvelables qui d'ailleurs se trouve limité par des facteurs d'intermittences climatiques et de grandes surfaces requises mais également vers un concept de décentralisation de l'énergie. En se heurtant à l'incapacité d'un stockage adéquat de l'énergie solaire, principale énergie renouvelable au Bénin, il advient de concrétiser l'idée de l'autoproduction, produire sa propre énergie pour l'utiliser ou la réinjecter dans le réseau, ce qui réduirait les coûts inhérents au transport. De plus, il serait totalement absurde de s'activer autant pour le déploiement de la production sans tenir compte de la gestion de la consommation. Ce point évoque la nécessite d'assainir le marché des équipements énergivores en leur exigeant un minimum de performance énergétique, aussi bien pour le système conventionnel que le solaire. En revanche, l'efficacité énergétique non prise en compte dans le transport et la distribution de l'électricité représenterait un trou noir dans cette démarche. Les pertes d'énergies dans le réseau constituent un facteur non négligeable et il conviendra d'élaborer d'autres outils juridiques pour harmoniser le schéma d'efficacité énergétique global.

Pour le Bénin, les enjeux dans cette transition énergétique sont de plusieurs ordres :

- Enjeux énergétiques : la réduction de la précarité énergétique, le développement de l'Electrification Hors-Réseau (EHR), l'assainissement du marché des équipements électriques (lampes, climatiseurs et réfrigérateurs), la promotion des foyers améliorés et combustibles de substitution ;
- Enjeux socioculturels et économiques : la réduction de l'écart entre ruraux et citadins facilitant la lutte contre l'exode rural, l'amélioration de l'organisation de la vie sociale, la réduction de la corvée physique, la réduction de la dépendance vis-à-vis de l'extérieur (importations d'électricité et des combustibles fossiles), le développement de l'économie locale par l'énergie distribuée (décentralisée, hors réseau), l'impact sur la santé, l'éducation, la sécurité, etc. ;
- Enjeux environnementaux : la préservation des forêts et de l'enrichissement naturel des sols, la lutte contre la pollution et réduction des gaz à effet de serre, la régulation des cours d'eau et lutte contre les inondations, l'adaptation aux changements climatiques, le renforcement de la résilience énergétique.

Les défis majeurs sont caractérisés par le déficit énergétique (dépendance) à résorber, le cadre favorable au développement des EnR et à l'investissement privé à améliorer, le développement continu des compétences, la prise en compte des aspects climatique, économique, social et genre ainsi que la mise en œuvre des stratégies définies par la PONAME [1] et la PONADER [2].

Connaissant mieux que quiconque leurs propres atouts (ressources naturelles, savoir-faire locaux, infrastructures…), les collectivités jouent un rôle facilitateur et incitateur majeur. Il leur revient d'associer acteurs publics et privés, pour faire émerger les démarches entrepreneuriales et innovantes nécessaires à la transition énergétique. Gisement important d'emplois non délocalisables, elle offre une opportunité de structurer de nouvelles filières économiques dans une logique de complémentarité entre territoires.

Les filières associées aux énergies renouvelables et aux solutions d'efficacité énergétique, bénéficient de plusieurs atouts, notamment le renforcement du cadre institutionnel, juridique et réglementaire favorable, la création récente de la Société Béninoise de Production Electrique (SBPE) en 2020 pour porter la production électrique notamment les grands projets d'énergies renouvelables, le développement de l'Electrification Hors-Réseau (EHR), la promotion de la maitrise d'énergie, la disponibilité des ressources énergétiques renouvelables ainsi que la disponibilité de cycles complets de formation (CAP, DT, Licence, Master, Doctorat, notamment à l'UAC, à l'UNSTIM et à l'ESMER avec des collaborations internationales), le dévouement du secteur privé et une société civile bien active (AISER, ONG et autres associations).

Les projets actuels, loin de prétendre être satisfaisants, représentent un grand pas dans l'atteinte des objectifs d'autonomisation. La subvention au profit de plusieurs projets d'entreprises privées pour des solutions d'énergie propre offgrid et ongrid (essentiellement solaire, dont 4 centrales solaires PV ongrid pour 50 MW); la construction d'une centrale solaire PV on-grid 25 MWc à Illoulofin (Pobè) avec extension à 50 MW ; du barrage hydroélectrique multifonction Dogo-bis 128 MW et 5000 ha d'irrigation ; la résilience du secteur de l'énergie aux impacts des changements climatiques au Bénin ; le programme solaire pour les ménages, les centres sociaux, de santé, de sécurité, scolaires et les unités de production ; le Plan Directeur EHR, notamment le développement des microcentrales solaires PV pour l'EHR, l'éclairage public à travers le projet « Lumières du Bénin »… sont la preuve des efforts fournis par le secteur.

III. Mix Energétique Responsable

Le mix énergétique désigne la répartition des différentes sources d'énergie primaire dans la consommation énergétique finale d'une zone géographique donnée. À l'échelle mondiale, ce mix est largement dominé par les énergies fossiles responsables des émissions des gaz à effet de serre (GES). Pour réduire ces effets et lutter efficacement contre le réchauffement climatique et la raréfaction des ressources fossiles, le modèle énergétique actuel doit évoluer vers un mix énergétique favorisant les sources

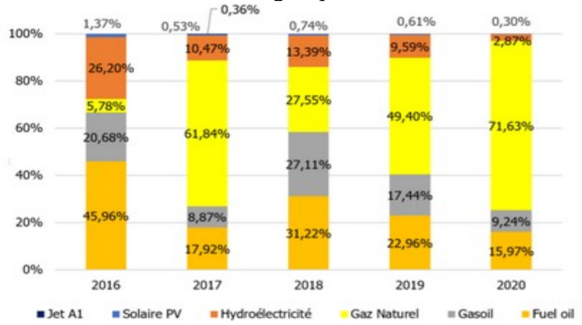

Figure 1 : Mix de production d'énergie électrique par forme d'énergie au Bénin sur la période 2016-2020 [3]

d'énergies renouvelables (EnR) présentes infiniment dans la nature telles que l'eau, le vent, ou encore le soleil... Au Bénin en 2020, le gaz naturel est la première forme d'énergie utilisée pour produire de l'énergie électrique avec 71,63%. Le solaire PV fait 0,30 % du mix par forme d'énergie contre 0,74% en 2018. Cependant, si la figure 1 confirme une réduction de la part des EnR dans le mix énergétique sur la période, il ne s'agit cependant pas d'un cas de diminution de l'énergie renouvelable, mais plutôt d'augmentation de l'énergie thermique due à la nouvelle centrale de Maria-Gléta qui assure désormais plus de 60% des besoins électriques du Bénin, et participe autant à la réduction de la dépendance électrique du Bénin vis-à-vis de l'étranger, dépendance qui avait jadis pour corollaires des délestages répétés, fréquents et prononcés avec des pertes économiques inestimables et un inconfort social pour tous.

Le mix énergétique responsable est pour nous, un développement optimal, soutenable et durable des énergies renouvelables et de l'efficacité énergétique ! Pour y arriver, nous avons instauré un cadre de gouvernance politique et réglementaire clair et incitatif, et devrons continuer à développer les compétences de tous les acteurs publics ou privés, mobiliser les financements et investissements et porter la dynamique d'un secteur de l'énergie en marche au Bénin, notamment à travers les 2 leviers de la transition énergétique qui sont la PONAME [1] et la PONADER [2]:

- la Politique Nationale de Maîtrise d'Energie (PONAME) à l'horizon 2030 a pour but de :
  - Réduire les consommations énergétiques d'au moins 25%
  - Gérer l'offre et la demande énergétique
  - Gérer de manière durable les ressources en biomasse et l'environnement
  - Mettre en place un cadre institutionnel et réglementaire efficace
  - Mettre en place un mécanisme de financement adéquat
- la Politique Nationale de Développement des Energies Renouvelables (PONADER) est bâtie autour de 5 principes directeurs et 7 axes stratégiques déclinés en 6 programmes opérationnels pour un montant d'environ 1087 milliards FCFA, et vise d'ici 2030 à :
  - Réduire les coûts de production d'au moins 10%, notamment grâce à l'hydroélectricité

- Augmenter la part de renouvelable à plus de 50% dans le mix énergétique
- Mettre en place un cadre de gouvernance favorable pour le développement des énergies renouvelables
- Favoriser l'exploitation durable et la valorisation optimale des sources d'énergies renouvelables

IV. Perspectives

L'ambition principale du Bénin est de réaliser l'autonomie énergétique [5]. Cela impliquera la consolidation et la diversification des ressources énergétiques ; l'amélioration de l'accès à l'énergie, en quantité et en qualité pour tous ; et le renforcement des compétences de tous les acteurs du secteur ainsi que le développement du contenu local dans les projets.

Les grandes priorités en matière d'EnR concernent le développement des EnR pour la grande production d'électricité (6 centrales solaires PV pour 100 MW, le barrage hydroélectrique Dogo-bis pour 128 MW) ; le développement des EnR pour la petite production d'électricité (solaire pour l'EHR, les infrastructures socio-économiques nationales et l'éclairage public) ; la valorisation durable et optimale de la biomasse énergie en combustibles domestiques (énergies propres de cuisson) ; la maîtrise de l'exploitation du bois-énergie ; la valorisation énergétique des déchets et ordures ; la normalisation et la promotion des foyers améliorés certifiés ; la gestion efficiente de l'offre et de la demande d'énergie (augmenter la production et réduire les pertes), le renforcement des investigations sur l'éolien (potentiel technique et valeur économique à des altitudes de 80 à 100 mètres).

La décennie 2021-2030 est donc celle de la transition énergétique au Bénin, et à titre d'illustration, la projection de la part des EnR dans le mix énergétique au Bénin se présente comme l'indique la figure suivante.

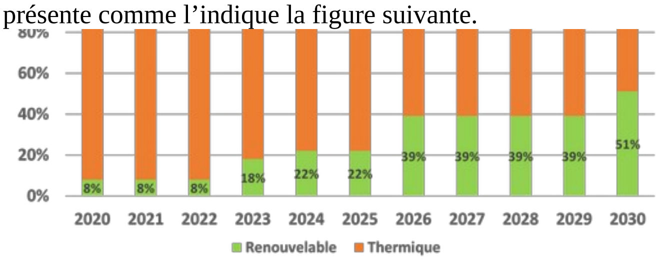

Figure 2 : Projection de la part des énergies renouvelables dans le mix énergétique au Bénin à l'horizon 2030

La vision d'atteindre un mix énergétique responsable repose sur la recherche constante et le maintien permanent des sept équilibres que sont :

- l'équilibre technique entre l'énergie disponible et la demande en énergie,
- l'équilibre financier entre le coût de production et le prix de vente de l'énergie,
- l'équilibre social entre les producteurs et les consommateurs d'énergie,
- l'équilibre écologique entre les systèmes naturel et humain,
- l'équilibre économique entre les investissements consentis et la croissance obtenue,
- l'équilibre climatique entre émissions et absorptions de gaz à effet de serre,
- l'équilibre environnemental entre impacts environnementaux et mesures de gestion.

V. Conclusion

Après avoir jugulé la crise énergétique, le Bénin engage au cours des 5 prochaines années, sa transition vers un mix énergétique responsable dans un cadre accéléré de développement économique et social durable porté par l'action du Gouvernement, et générant de plus en plus d'opportunités réelles d'emplois notamment vertes au profit de la jeunesse, qui est appelée à s'impliquer davantage pour l'accès de tous à des services énergétiques fiables, durables et modernes, à un meilleur coût.

Cependant le développement du capital humain et des compétences du secteur, la recherche-développement et l'innovation ainsi que la connaissance approfondie du potentiel national d'EnR notamment en matière d'éolien et de biomasse énergie requièrent davantage d'efforts du Gouvernement et de ses partenaires.

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Energie et Développement durable : comment changer de paradigme

Michel Boko
Académicien (ANSALB)
Cotonou, République du Bénin
bokomichel@gmail.com

***Résumé*—Toute vie et toute activité de production sont indissolublement liées à une source d'énergie. Et pourtant, l'utilisation de certaines formes d'énergie peut handicaper le développement de la vie et aussi la production, donc le développement. Historiquement, les décideurs politiques insistent bien volontairement sur le dilemme entre le développement social et économique et l'utilisation des ressources énergétiques comme la biomasse, les hydrocarbures fossiles, l'énergie nucléaire.**

Face à la prise de conscience des risques coûteux liés à l'utilisation de certaines ressources énergétiques, les environnementalistes ont convenu de procéder par standardisation des effets induits sous le vocable de bilan carbone. Le bilan carbone constitue une mesure de comparaison afin de justifier les choix politiques et technologiques que les décideurs politiques pourraient être amenés à faire.

Mots clefs — énergie, pollution, environnement, développement durable

VI. Introduction

Depuis l'origine de l'humanité, l'être humain aspire à se développer, non pas au sens biologique, mais aussi au sens sociologique et spirituel et matériel. Le développement, dans son acception matérielle, passe par la production et les échanges de biens de consommation. Quel que soit le type d'organisation socioéconomique, le développement se mesure en termes de quantité de biens de consommation produits. Bien entendu, le concept de développement humain durable inclut d'autres indicateurs.

L'Indice de Développement Humain (IDH) est un indice créé par le Programme des Nations Unies pour le développement (PNUD) en 1990 pour mesurer le niveau de développement humain sur des critères autres que la seule production économique (taux d'éducation, espérance de vie, niveau de vie, etc.). C'est aujourd'hui le principal indicateur utilisé pour mesurer le bien-être individuel et collectif dans une région donnée.[1]

Historiquement, les décideurs politiques insistent bien volontairement sur le dilemme entre le développement social et économique et l'utilisation des ressources énergétiques comme la biomasse, les hydrocarbures fossiles, l'énergie nucléaire.

Toute vie et toute activité de production sont indissolublement liées à une source d'énergie. Et pourtant, l'utilisation de certaines formes d'énergie peut handicaper le développement de la vie et aussi la production, donc le développement. A titre d'exemples, on peut citer les catastrophes industrielles qui causent des dégâts matériels et des pertes de vies humaines par dizaines, voire par centaines.

Il y a donc trois dilemmes à résoudre : Peut-on atteindre le développement durable sans changer la typologie des énergies utilisées actuellement ?

TABLE I. LES INDICES DE DÉVELOPPEMENT HUMAIN ET LE CONCEPT DE DÉVELOPPEMENT DURABLE

	Indices synthétiques			**Tableaux de bord**
Méthodes→ ↓valeurs	Satisfaction *(enquête directe), parfois couplée" avec une donnée écologique*	Pondération d'indices hétérogènes sans unité de compte commune	PIB "corrigé" (variables monétarisées) ou unités écologiques physiques	Bilans cohérents et suivis sans indice synthétique
Notion de vie jugée satisfaisante	Mesures globales du bien-être "subjectif"			Bien-être subjectif selon différents aspects de la vie
Dominante sociale ou socio-économique, développement humain		Ex: IDH, Indicateur de Santé Sociale, BIP40 ...	PIB corrigé de Nordhaus-Tobin (1973)	Tableaux de bord d'indicateurs sociaux ou socioéconomiques
		IBEE (Osberg-Sharpe)		
Dominante environementale, avec plus ou moins de critères sociaux	Happy planet index	Moyenne pondérée de performances environnementales (ESI)		Tableaux de bord environnementaux ou socio-environnementaux

Source : Jean Gadrey, 2009. Encyclopédie du développement durable.

VII. La probématique du changement climatique : La question du bilan carbone et l’analyse de cycle de vie

Dans les études environnementales, on parle couramment d’analyse de cycle de vie (ACV), ou Life Cycle Assessment (LCA) consistant à quantifier l’ensemble des impacts environnementaux d’un produit ou d’un processus, de sa conception jusqu’à sa fin de vie. Il s’agit de quantité de matériaux bruts ou d’énergie utilisés ou encore de gaz à effet de serre émis. Cette méthode permet de faire une comparaison à valeur écologie des options énergétiques.[2]

Nous pouvons donc faire un répertoire de différentes sources énergétiques, afin d’en avoir une vue plus «écologique» dans le but d’éclairer le choix des décideurs politiques et financiers.

Pour les éoliennes, les émissions de GES par KWH produit varient entre 59,19 gr CO_2 eq/KWH (pour une éolienne de 850 KW, à 52,61 gr CO_2 eq/kwh (pour une éolienne de 3000 KW

Si nous prenons le cas de l’énergie nucléaire, on constate que les résultats varient du simple au centuple (de 1,8 gCO_2 eq/kWh à 200 gCO_2 eq/kWh), avec une valeur moyenne est comprise entre 20 et 50 gCO_2 eq/kWh. [3]

Quant à l’énergie hydro-électrique, sur la base des travaux de Lerche Radaal et al., qui fait la synthèse de des résultats de 39 études sur les émissions de gaz à effet de serre liées aux barrages hydroélectriques, on constate qu’un barrage hydroélectrique a un impact d’environ 35 gCO_2 eq par kWh produit tout au long de sa vie. Ici, il faut tenir compte des superficies inondées pour les barrages ayant unréservoir.

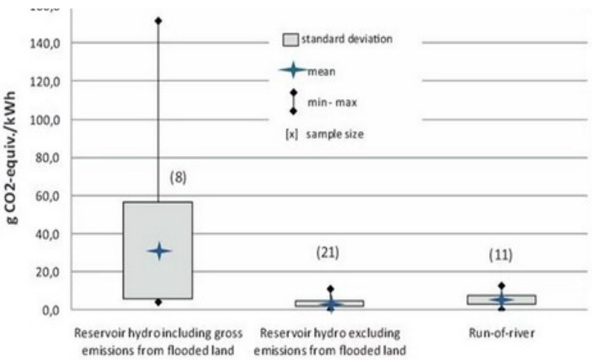

Fig. 1. Les émissions de GAS des barrages hydroélectriques à partir d’un échantillon de 39 barrages. (Source: Lerche Radaal et al.)

Sur la figure ci-dessus, on retrouve à gauche les résultats pour les ouvrages ayant un réservoir et dont l’impact sur les zones inondées en matière de GAS a été évalué dans l’étude, au milieu les ouvrages avec réservoir mais dont l’impact n’a pas été quantifié dans l’ACV, et enfin, à droite les ouvrages sans retenue d’eau.

L’impact estimé en matière de GES des centrales à charbon diverge suivant la méthodologie ou le type de technologie de combustion utilisée. Néanmoins, la majorité de la communauté scientifique s’accorde sur des émissions tournant plus ou moins autour de 1 000 g CO_2 eq par kWh produit.

Selon l’ADEME, agence de la transition écologique, en France, un panneau photovoltaïque émet en moyenne 55 gCO_2 par KWh produit. Il faut trois ans à un panneau solaire pour qu’il ait le temps d’amortir sa propre fabrication. On estime que cette compensation est durable, car la durée de vie d’un panneau solaire est estimée entre 25 et 30 ans.

VIII. La question de l’équité intergénérationnelle

L’empreinte écologique permet de quantifier les besoins humains, mesurés en « hectares globaux », par rapport aux capacités de la Terre à y répondre à long terme mesurées en «hectares globaux disponibles».

Lorsque les besoins de l’humanité dépassent les capacités de la terre, les écosystèmes et les ressources naturelles ne sont plus capables de se régénérer pleinement, entraînant leur dégradation, leur raréfaction, voire leur disparition. Dès lors, l’humanité puise dans des réserves qui ne seront plus disponibles pour les générations futures.

Aujourd’hui, on estime que les besoins de l’humanité dépassent de 50 % cette capacité de renouvellement, d’où l’idée que nous « consommons 1,5 Terre » ou que nous vivons « à crédit ».

Il faudrait 1,5 Terre pour répondre durablement aux besoins actuels de l’humanité. En d’autres termes, nous ne sommes pas sûrs de pouvoir continuer les modèles de développement actuels, si les sources d’énergie venaient à être épuisées. Ce concept sous-entend que les générations présentes pourraient épuiser toutes les ressources de la terre et sa capacité de renouvellement, au point que les générations futures seront en panne de développement. Autrement dit, les besoins humains dépasseraient l’écocapacité de la planète Terre. Si cela peut être vrai pour les ressources renouvelables, il sera encore plus vrai pour les ressources non renouvelables comme les combustibles fossiles. La production d'électricité à partir de combustibles fossiles représente 2/3 de l'électricité mondiale. Or les réserves se raréfient, dans un contexte d'augmentation des prix. L'agence internationale de l'énergie a estimé que la demande mondiale d'énergie pourrait augmenter de 45 % d'ici l'an 2030, notamment en raison du développement démographique et de l'industrialisation de pays comme la Chine et l'Inde, qui comptent à eux seuls plus de 2 milliards d'habitants. La consommation d’électricité devrait croître 2 fois plus vite que la consommation moyenne d’énergie.

La production d’énergies fossiles (charbon, gaz naturel, pétrole) représente encore aujourd'hui plus de 80% de la production totale d’énergie primaire dans le monde. Or, les réserves énergétiques de la planète ne sont pas inépuisables : au rythme de consommation actuel,

- le pétrole va arriver à épuisement d'ici à 54 ans,
- le gaz d'ici à 63 ans,
- le charbon d'ici à 112 ans et
- l'uranium d'ici à 100 ans (pour les ressources identifiées).

Par ailleurs, les réserves sont inégalement réparties, entraînant ainsi une dépendance forte de nombreux pays, avec les conséquences que cela peut avoir en termes de coût d'approvisionnement, mais aussi en termes de conflits militaires pour s’assurer l’approvisionnement en ressources énergétiques.

Pour préserver les ressources, il est préconisé de développer des énergies renouvelables comme moyen de production d'énergie : hydraulique, éolien, solaire photovoltaïque, géothermie, biomasse, énergies marines. Mais, le changement climatique annoncé peut réduire les possibilités de production de l'énergie d'origine hydraulique. C'est un nouveau défi encore peu étudié jusqu'alors.

Le laboratoire Pierre PAGNEY « Climat, Eau, Environnement et Dynamique des Ecosystèmes » (LACEEDE) de l'Université d'Abomey-Calavi, organise dans les semaines à venir la 4ème conférence internationale de Friend Water sur l'hydrologie des grands fleuves d'Afrique. Ce sera l'occasion, je l'espère, d'étudier la dynamique hydrologique dans la perspective des changements climatiques et consécutivement, de la réduction des écoulements, ou de leurs caractéristiques, étant entendu que la succession de pluviométries excédentaires et déficitaires mettra à rude épreuve la planification de la fourniture de l'hydroélectricité. En effet, on a l'habitude de dire ou d'écrire que l'hydroélectricité peut remplacer efficacement les énergies fossiles. En d'autres termes, le développement de l'hydroélectricité permettrait d'anticiper l'épuisement des réserves d'énergies fossiles

IX. L'EFFICACITÉ ÉNERGÉTIQUE.

L'efficacité énergétique est le premier levier de réduction de la consommation des ressources naturelles par : l'augmentation du rendement des installations et la limitation des pertes lors de la production, du transport (1) et de la distribution (2) , grâce à des technologies plus performantes. Les spécialistes nombreux dans cette salle nous donneront de plus amples et plus solides informations sur les options. Néanmoins, cela ne résout pas la problématique environnementale liée à l'utilisation des sources d'énergie, car aucune source n'est sans nuisance pour la planète : la production et l'utilisation d'énergie viennent incontestablement au tout premier rang des causes de pollution de la biosphère. La consommation d'énergie fossile produit chaque année environ 8 milliards de tonnes de CO_2 , ce qui constitue une contribution significative à l'augmentation de la température de la terre par l'effet de serre. Chaque année, l'humanité utilise 3 milliards de tonnes de bois, ce qui est source de déforestation, à laquelle il faut ajouter les 2 millions de décès par la pollution de l'atmosphère intérieure des habitations.

La production, le transport et l'utilisation des énergies fossiles (4 milliards de tonnes de pétrole, 3 milliards de tep pour le charbon, 2,5 milliards de tep pour le gaz naturel) sont sources de nombreuses pollutions de la biosphère (atmosphère, écosphère et de l'hydrosphère).

L'énergie nucléaire serait-elle alors moins dommageable à la biosphère ? Si l'on fait table rase de toute attitude « émotionnelle » liée à l'utilisation de l'énergie nucléaire à des fins militaires, le seul vrai problème lié à l'énergie électronucléaire est celui de la « gestion des déchets nucléaires», puisque leur durée de demi-vie serait de 100.000 ans, d'où un sérieux problème de stockage. A titre d'exemple, on estime que si les USA voulaient subvenir à tous leurs besoins en électricité à partir de centrales nucléaires, il leur faudra gérer des déchets équivalents à l'explosion 8 millions de bombes Hiroshima. Au problème de stockage des déchets radioactifs, il faut ajouter celui de la pollution thermique des eaux superficielles, du fait de la nécessité de refroidir les radiateurs. Mais le problème de pollution thermique se pose aussi pour les centrales à fuel et à charbon. La pollution thermique des eaux fluviales ou littorales se traduit par un réchauffement dont les conséquences sont catastrophiques pour les espèces aquatiques, marines ou d'eau douce. En effet, dans les systèmes énergétiques à combustion, environ 60 % de l'énergie potentielle est perdue sous forme de basses calories inutilisables, car le rendement thermodynamique n'excède pas souvent 40 %.

Depuis la signature du Protocole de Montréal en mai 1988, les travaux de synthèse bibliographique réalisés par les experts du GIEC permettent d'affirmer que la consommation des sources d'énergie fossiles constitue le premier facteur de changement climatique d'origine anthropique.

La méthode du cycle de vie permet aujourd'hui de mesurer la quantité globale des émissions d'une source d'énergie. [4, 5]

TABLE II. LES ÉMISSIONS DES ÉNERGIES POUR LA PRODUCTION D'ÉLECTRICITÉ EN ÉQUIVALENT CO2 (CO2E) EN GRAMME PAR KILOWATTHEURE D'ÉNERGIE FINALE :

Combustible	Emission de CO_2
Biomasse (déchets de bois avec turbine à vapeur)	***32 gCO₂/ KWh***
Eolien (en mer)	***9 gCO₂/ KWh***
Eolien (en terre)	***10 gCO₂/ KWh***
Hydroélectricité	***10 gCO₂/ KWh***
Géothermie	***38 gCO₂/ KWh***
Electricité (chauffage)	***210 gCO₂/ KWh***
Gaz naturel	***210 gCO₂/ KWh***
Pile à combustion	***664 gCO₂/ KWh***
Centrale (fioul-vapeur)	***730 gCO₂/ KWh***
Pétrole lourd	***778 gCO₂/ KWh***
Centrale à charbon	***1058 gCO₂/ KWh***

Source : Bilan GES de l'Ademe, méthode dite « saisonnalisée par usage ».

X. UNE APPROCHE DE SOLUTION D'ÉCHELLE GLOBALE : LE PROJET DESERTEC, UN ESPOIR DÉÇU ?

Dans cette présentation, il n'est question que de l'énergie solaire photovoltaïque, mais pas du solaire thermique dont l'utilisation industrielle et domestique est encore limitée. Pendant les années 2000, la nécessité de diminuer les émissions de gaz à effet de serre, la perspective du pic pétrolier et les doutes sur les solutions pour la gestion des déchets radioactifs et sur les risques liés à cette source d'énergie, rendent le solaire thermique plus attractif. Les chauffe-eau solaires connaissent un développement rapide dans certains pays, en particulier en Chine, et des projets industriels de grande taille sont réalisés aux États-Unis, en Espagne, au Moyen Orient, en Australie et au Maroc. Mais la baisse rapide des coûts du solaire photovoltaïque au début des années 2010 fait chuter les projets du solaire thermique individuel, devenu moins attractif, et du solaire thermodynamique, devenu moins compétitif.

Le grand projet international Desertec n'a finalement pas vu le jour. **Desertec** était un projet éco-énergétique de grande envergure qui prévoyait l'exploitation du potentiel énergétique solaire des déserts d'Afrique du Nord et du Moyen Orient afin d'approvisionner durablement les régions avoisinantes (en particulier l'Europe) en électricité renouvelable. Le concept Desertec fut développé à l'origine par la « Coopération transméditerranéenne pour l'énergie renouvelable » (TREC pour Trans-Mediterranean-Renewable Energy Cooperation. LaFondation Desertec voit le jour en 2003 sous les auspices du Club de Rome et du Centre national de recherche sur l'énergie en Jordanie (NERC). Les « pendants » industriels de la fondation sont respectivement la Dii GmbH (fondée sous le nom de Desertec Industrial Initiative) et MedGrid, lesquels visent à promouvoir l'implantation du concept Desertec dans la région Union Européenne-Moyen Orient et Afrique du Nord. Quant à l'organisation Sahara Green, elle continue à promouvoir toutes les initiatives qui visent à exploiter le soleil des déserts pour les reverdir.

Initialement Desertec visait à la fois à répondre en grande partie aux besoins des pays producteurs d'Afrique du Nord et du Moyen-Orient, et à couvrir jusqu'à presque 20 % de la demande d'électricité en Europe.

Depuis, l'objectif initial d'exportation d'énergie vers l'Europe a été temporairement abandonné car il n'était pas concurrentiel avec les solutions locales au continent européen.

XI. En guise de conclusion

Il est loisible de noter que l'atteinte des objectifs du développement durable passe nécessairement par la production de biens et de services, nécessitant l'utilisation de matières premières et de ressources énergétiques. Nous constatons donc que cela engendre une génération de nuisances à l'environnement, soit sous forme de gaz à effet de serre responsable de la crise climatique, soit sous forme de déchets dont la destination finale est encore difficile à imaginer. On en revient donc aux six principes fondamentaux de l'écologie industrielle que sont :

1) **L'écocapacit**é, c'est-à dire la capacité d'un écosystème à absorber les nuisances et à se régénérer ;

2) **La précaution,** c'est-à-dire la prise de dispositions de manière à empêcher l'avènement d'incident, voire d'accident incontrôlable ;

3) **L'anticipation**, c'est-à-dire la mise au point de technologies aptes à devancer les événements dangereux prévisibles ;

4) **La prévention,** qui implique les dispositions propres à éviter ou à réduire la gravité des événements éventuels ;

5) **L'équité** inter et transgénérationnelle, qui est un concept philosophique et métaphysique qui implique un bénéfice égalitaire des biens et services sans tenir compte du sexe et de la catégorie sociale, mais aussi à réserver aux générations la possibilité de faire leur propre choix de modèle de consommation et de développement, autrement dit, ce principe consiste à ne pas imposer aux générations futures un modèle de développement qui serait la conséquence de notre consumérisme effréné ;

6) Enfin **l'efficacité énergétique** qui consiste à éviter le gaspillage des ressources, étant entendu qu'à l'échelle de la vie humaine, ces ressources ont une durée de vie limitée ou existeraient en quantités limitées. Nous sommes là au cœur de la définition première du développement durable. [6, 7]

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Vers un pacte de solidarité énergétique en Afrique de l'Ouest pour l'industrialisation de la sous-région. Quelles coopérations avec l'Europe ?

Claude Fischer-Herzog
Directrice d'ASCPE
Les Entretiens Européens & Eurafricains
Paris, France
claude.fischer-herzog@entretiens-europeens.org

***Résumé de l'intervention*—La conférence s'inscrit dans le débat sur le « monde d'après », dont chacun espère qu'il sera différent. La crise globale sera-t-elle une opportunité pour changer nos modèles de croissance ? Aller vers la transformation du capitalisme en Europe, inventer de nouvelles relations permettant à l'Afrique de bâtir une croissance plus inclusive et son émergence dans la mondialisation ? Créer de nouveaux modes de gouvernance ici et là-bas ?**

Les moyens mis en œuvre en Europe en Afrique pour faire face aux défis sont sans commune mesure : injections massives de liquidités et endettement permanent en Europe, levée du moratoire de la dette et fonds de tirage spéciaux très insuffisants en Afrique. On parle de « new deal », de « plan Marshall » pour aider l'Afrique, on se gargarise de slogans alors que les besoins sont immenses. Et à l'heure de la COP 26, il pleut des annonces pour aider l'Afrique à réussir sa « transition énergétique ».

L'Afrique est riche de sources énergétiques diversifiées dont elle a besoin pour produire, transformer ses matières 1ères sur place (mines et agriculture), se nourrir, se soigner et répondre de manière adaptée aux besoins des secteurs industriels et des territoires. Or, l'électrification des régions reste à faire.

Quelle est la stratégie de l'Afrique de l'Ouest pour réaliser son interconnexion et valoriser les projets décentralisés d'électrification ? Un pacte de solidarité énergétique est-il envisageable ? Tout en respectant les atouts de chaque pays, il pourrait se fixer l'objectif d'un marché régulé où l'électricité – qui n'est pas une marchandise comme une autre mais un bien public essentiel - bénéficierait de politiques publiques et de garanties nationales. Les investissements dans la construction de centrales, des réseaux de transports et de distribution sont longs et lourds, ils nécessitent des partenariats public/privé, et des soutiens publics internationaux.

Or, l'Union européenne a tendance à conditionner ses aides à ses propres critères et à imposer ses modèles avec une priorité aux énergies renouvelables et à l'efficacité. Au contraire, et au regard des effets pervers que cette stratégie crée en Europe, ne doit-elle pas soutenir l'Afrique dans la construction d'un mix diversifié utilisant tous ses atouts (y compris l'uranium) et pour le financement des infrastructures ? Comment travailler avec les bailleurs de fond internationaux ? Comment organiser une mobilité positive pour le transfert de technologies et la formation des compétences sur place ? Comment mieux associer les sociétés civiles aux choix collectifs et les préparer aux coopérations interrégionales ?

VIII. Introduction

Je suis directrice des Entretiens Européens & Eurafricains. C'est un réseau d'acteurs publics et privés qui a l'ambition de s'approprier tous les sujets de société, et d'infléchir les politiques publiques qui sont trop souvent décidées sans nous ! Or, celles-ci nous engagent et nous voulons y participer !

Vous pourriez vous demander ? Avec quelle légitimité ? Avec celle d'une femme, engagée depuis 50 ans pour « changer le monde », fervente militante du rapprochement entre les sociétés civiles de tous les pays pour un dialogue avec les institutions à tous les niveaux, et depuis une dizaine d'années entre celles d'Europe et d'Afrique pour un renouvellement des relations entre nos continents.

Les Entretiens Eurafricains, c'est plusieurs milliers de personnes d'horizons divers, de sensibilités différentes, de plusieurs pays d'Europe et d'Afrique. C'est une plateforme UE/Afrique(s) qui organise des séminaires à Paris, c'est une association Eurafrique 21 qui organise des rencontres en Afrique de l'Ouest, c'est des colloques Eurafricains à Bruxelles, Ouagadougou, Paris, Dakar... C'est un festival de cinéma Eurafricain pour mieux découvrir nos cultures et nos identités...

Le colloque de Dakar a eu lieu sur le thème « l'Union régionale, moteur d'une croissance inclusive en Afrique de l'Ouest ? », et plus récemment, une conférence a eu lieu sur « regards croisés sur la crise globale ». Parmi les recommandations pour l'Afrique de l'Ouest, **un pacte de solidarité énergétique pour l'industrialisation de la sous-région.** C'est sur ce thème que j'aimerais axer mon intervention aujourd'hui.

Ce sujet se pose avec encore plus d'acuité avec la crise sanitaire et économique, et avec la crise climatique... et même avec la crise énergétique et la flambée des cours du pétrole et du gaz. Car, paradoxalement, et j'y reviendrai, les pays africains ne sont pas sûrs de pouvoir en profiter pleinement.

Et la solidarité, mieux vaut peut-être la penser et l'organiser entre vous, sans attendre les promesses de l'Occident !

Elle doit pouvoir s'organiser dans chaque sous-région. Je suis convaincue que c'est là que les acteurs trouveront la meilleure stratégie de développement, en fonction des atouts régionaux et pourront mettre en œuvre les interconnexions énergétiques les plus efficaces. Ce qui ne s'oppose pas à des coopérations interrégionales et à l'échelle de tout le continent, bien au contraire.

IX. Quelques mots sur le contexte global.

On est en pleine COP 26, et les annonces pour une « solidarité » avec l'Afrique pleuvent ![4] Comme à chaque COP ! Comme à chaque Sommet !! Or, on le sait de la parole aux actes, il y a « une vallée du désert » si vous me permettez l'expression. La promesse de 100 milliards par an faite en 2009 à Copenhague, renouvelée à la COP 21 à Paris et réitérée à Glasgow, pour aider le continent qui sera fortement impacté par les dérèglements climatiques (alors qu'il émet 3% des EGES) est loin d'être réalisé 12 ans après...

Et pas de faux espoirs : le « monde d'après » que chacun espérait plus solidaire après la crise sanitaire, n'est pas encore construit ! Et je crains avec l'économiste Dani Rodrik[5] que cette crise « n'amplifie au contraire les caractéristiques politiques dominantes de chacune des nations », et avec Patrick Artus « une phase de durcissement du capitalisme »[6] .

Alors qu'elle a frappé plus durement l'Afrique[7] et aggravé les inégalités d'accès aux biens essentiels comme l'eau, l'éducation, la santé et l'électricité[8] entre nos deux continents (et en leur sein), les moyens mis en place sont sans commune mesure : des milliers de milliards d'euros en Europe, quelques centaines de milliards de dollars en Afrique... Les droits de tirage spéciaux du FMI pour l'Afrique d'un montant de 235 milliards sont très insuffisants, et la « générosité » des pays de l'UE pour « donner » une partie de leurs DTS (65 milliards dont ils n'auront pas l'utilisation) semble bien faible, pour ne pas dire condescendante, au regard des besoins massifs.

Nul doute que les fractures entre les pays industrialisés d'un côté et une économie de survie de l'autre vont se multiplier.

Or l'Afrique a besoin de créer de la valeur ajoutée et émerger dans l'économie mondiale où elle ne représente encore que 3%.

Dans ce contexte, l'appel des économistes africains à profiter du « choc systémique planétaire » pour construire une voie de développement endogène (Kako Nubukpo), ou à « se réinventer pour bâtir son économie sur ses propres forces[9] » (Papa Dembe Thiam), ou encore de retourner les impacts de la crise en atouts (Vera Songwe) pour construire une croissance inclusive, est salutaire.

Quel type de croissance ? Beaucoup misent sur une économie de services et du numérique. Mais je me permets d'attirer votre attention : le numérique peut être un miroir aux alouettes quand on ne maîtrise pas les données... et les services sans industries ne sont pas viables ! Notre expérience européenne doit servir à l'Afrique...

X. Bâtir une « InduService »

L'Afrique doit s'industrialiser, bâtir don InduService. Elle est riche en hommes (et femmes), en matières premières et en ressources agricoles, mais elle ne les transforme pas. Pourquoi ? La réalité des échanges Nord/Sud et l'intérêt du Nord à continuer à acheter les matières premières et les terres rares (pour sa propre transition écologique !) ne sont-ils pas des freins majeurs à l'investissement dans les industries de transformation... et dans les infrastructures nécessaires à la production énergétique elles-mêmes ?

Certes tout ne s'explique pas par le type de relations que nous avons développé sur la longue période. La preuve en est justement la « crise énergétique » que l'Europe subit de plein fouet avec l'explosion des prix du pétrole et du gaz. Après avoir vécu dramatiquement les impacts de la chute des prix des matières 1ères, le prix du baril à 85 dollars (le plus haut depuis 2018), et celui du gaz (entre 30 et 50 dollars, +250% !) devraient représenter une embellie pour l'Afrique et les pays producteur qui font face à des déséquilibres budgétaires colossaux. Mais la sous-production imposée par l'OPEP [10], les contrats gaziers à long terme reconduits avec l'Europe avant la hausse, la hausse de la consommation intérieure... mais aussi les dépenses improductives des états qui ne savent pas (ou ne veulent pas) diversifier leurs économies et leur mix énergétique, ne lui permettront pas d'en profiter.

D'où l'urgence de changer de modèle de croissance !!

XI. Un gap énorme entre le potentiel et l'accès à l'énergie

L'Afrique a un potentiel énergétique énorme, avec le gaz et le pétrole, mais aussi l'hydraulique au Centre, le charbon à l'Est, l'uranium dans 34 pays, la biomasse dans les zones rurales, du soleil partout et elle est entourée de la mer... Et les Africains font preuve d'innovations technologiques adaptées à leur réalité [11]. Mais les investissements ne décollent pas.

Avec un taux d'électrification moyen de 43% et près de 33 pays africains (sur 54) qui sont en dessous du seuil des 20% d'électrification, il y a un gap énorme par rapport aux

4 L'Allemagne, la France, les USA et l'UE ont exprimé «une envie de solidarité» selon la formule du président français et promis 8,5 milliards pour décarboner l'Afrique du Sud. Mais que valent ces promesses quand ils sont incapables de financer une transition juste en Pologne ?

5 Voir son article dans Les Echos : https://www.lesechos.fr/idees-debats/editos-analyses/le-covid-19-une-crise-qui-ne-va-rien-changer-1193461

6 Voir « Le grand entretien » dans les Echos des 4 et 5 septembre 2020.

7 La fermeture des frontières et l'arrêt des échanges la chute des prix des matières premières, ont provoqué des conséquences en chaîne sur les productions locales avec des pertes évaluées entre 37 et 79 milliards de dollars selon la BAD – dont 5 dans le secteur agricole. La diminution de l'argent de la diaspora (moins 35% en moyenne), la prudence des investisseurs ont entraîné une récession de 2,9% à 5% selon la Banque mondiale, alors que la population ne cesse de croître, menaçant la moitié des emplois et une augmentation de 50 millions de pauvres, et une situation précaire pour les populations dont la majorité dépend du secteur informel.

8 Rappelons que 640 millions n'ont pas accès à l'électricité, la pénurie d'eau touche 40% de la population.

9 https://www.letemps.ch/economie/papa-demba-thiam-covid19-devenir-une-chance-lafrique

10 A titre d'exemple, le Nigeria ne produit que 1,47 million de barils de pétrole/jour, alors que sa capacité de production est de 2 millions.

11 Voir le projet de kits photovoltaïques au Burkina Faso, au Mali à Madagascar et en Guinée pour 500 000 personnes

besoins en énergie du continent pour se développer. Selon des chiffres compilés par la Banque mondiale, la production de 48 pays d'Afrique subsaharienne équivaut, aujourd'hui, à celle d'un seul pays européen de taille moyenne comme l'Espagne !

Rien qu'en Afrique de l'Ouest, ils sont 250 millions à ne pas avoir accès à l'électricité (640 millions dans toute l'Afrique). Selon l'AIEA, la consommation d'un habitant africain représente environ 200 kWh/an, contre 7000 en Europe et 13000 aux Etats-Unis. Et les choses risquent de s'aggraver dans un contexte de croissance démographique, où la demande croit plus vite que l'offre.

Je me permettrai quelques éléments de diagnostic complémentaires :

- le marché ouest-africain n'attire pas les capitaux pour les investissements dans les infrastructures ; l'argent et les garanties publics sont insuffisants pour lever des fonds privés. Or les entreprises occidentales ont de fortes exigences : fonds et garanties publics, mais aussi une rentabilité des projets de 100%, un prix de l'électricité au prix coûtant.
- Les critères des bailleurs de fonds posent problème : ceux de l'UE, du FMI ou de ceux de la Banque mondiale... j'y reviendrai.
- Les rivalités entre les états et la faiblesse des coopérations prive la région de politiques solidaires.

Les conséquences sont graves :

- Inégalités croissantes entre les pays et au sein de chacun d'entre eux entre les centres et les périphéries ; les villes et les campagnes.
- Prix élevés de l'électricité, deux fois plus en moyenne en Afrique que dans le monde avec de gros écarts entre les pays.

Un taux d'électrification qui va de 64% au Ghana (55,8% en Côte d'Ivoire (56,5% au Sénégal, 55,6%) Nigeria) à 20% au Burkina Faso et même 16% au Niger où pourtant la France exploite l'uranium depuis des décennies.

XII. Quel mix énergétique pour l'Afrique ?

L'Afrique a besoin de toutes ses sources pour faire face aux besoins massifs si elle veut s'industrialiser, et développer sa croissance et l'emploi. Elle doit pouvoir développer un mix diversifié et « décarboné autant que faire se peut » ! Car les fossiles représentent encore 82%, avec une forte progression du gaz (28%) derrière le pétrole légèrement en baisse (42%) et le charbon (22%), les EnR représentant 8% (dont 6 pour l'hydraulique). Et il est utopique de réclamer une Afrique « zéro carbone ».

Par contre, elle peut développer ses énergies renouvelables et l'hydraulique, améliorer les conditions de production et d'exploitation des fossiles (et relancer les projets de CCS pour stocker le CO2), et je suis convaincue avec Mikhaïl Chudakov, Directeur général adjoint de l'AIEA et Chef du Département de l'énergie nucléaire depuis février 2015, que « l'énergie nucléaire pourrait faire partie de la solution pour un nombre croissant de pays d'Afrique », avec des transferts de technologies adaptées, et de connaissances et d'expériences pour une gestion des combustibles usés et des déchets nucléaires[12].

Refuser le nucléaire à l'Afrique au nom de la sûreté et de l'instabilité politique, exiger une « Afrique 100% solaire » comme on l'entend parfois en Europe au nom du climat, semble bien irresponsable ! Doit-on rappeler que le nucléaire a permis la prospérité en Europe au sortir de la guerre ? Pourquoi en priver l'Afrique qui rappelons-le a de l'uranium ? Quant au soleil, il n'a jamais fait de solaire. Il faut des panneaux photovoltaïques (produits en Chine) et de la grande eau pour les laver quand ils sont recouverts par la latérite ou le sable ! Et on devra avoir un débat sur ses coûts, car on entend tout et n'importe quoi.

L'Europe n'a pas de leçon à donner quand son mix énergétique est lui aussi composé à 80% de fossiles (20% d'électricité), et qu'elle ne respecte pas les engagements pris lors de la COP 21. Et de quel droit s'opposer au financement de centrales thermiques au Burkina Faso par la Banque Mondiale, sous prétexte qu'elles produisent du CO2 ? En Europe, l'Allemagne en a rouvert elle-même après la décision de fermer ses centrales nucléaires (et on continue à inonder le continent de nos voitures d'occasion polluantes, ou de nos déchets électroniques...).

L'Afrique doit doubler les capacités de production selon la BAD (passer à 320 GWH), effectuer 130 millions de nouveaux branchements au réseau et 75 millions hors réseau, et permettre à 150 millions de foyers de disposer de solutions de cuisson propres, et investir entre 60 à 90 milliards de dollars par an pour atteindre les objectifs qu'elle s'est fixés pour un accès de tous à l'électricité à l'horizon 2030. Un défi gigantesque !

Mais les bailleurs de fond imposent leurs critères. La BAD a promis 12 milliards de dollars sur ses ressources propres au cours des cinq prochaines années, mais pas pour les projets nucléaires. En Afrique de l'Ouest, le 11éme Fed européen a centré ses interventions sur la priorité aux ENR et l'efficacité (comme si le problème pour l'Afrique était de réduire sa consommation !) et sur la réglementation et l'intégration d'un marché régional pour stimuler le secteur privé et au prétexte d'attirer les capitaux.

Pourtant, au vu de ses résultats, l'Europe ne devrait pas imposer ses modèles. La construction d'un marché libéralisé, régi par les règles de la concurrence en 2009 a créé d'énormes effets pervers et aujourd'hui les états ont tendance à renationaliser leur politique énergétique. Le « Green deal » qui favorise les renouvelables a créé un marché volatil qui discriminent les autres sources. Les investissements nucléaires sont dissuadés et les états anti-nucléaires sont vent debout contre le financement des investissements malgré un parc qui a fait la prospérité de l'Europe, et qui doit être renouvelé. (Je rappelle que le nucléaire ne produit pas de CO2 et que le remplacer par des EnR intermittentes qui nécessitent une base pilotable est complètement aberrant, surtout si cette base est en gaz).

XIII. Mettre l'électricité au cœur d'un pacte de solidarité régional

12 Voir le Supplément de La Lettre des Entretiens Européens « La solution existe. Manque le courage de la décision ». Avril 2021.

L'Afrique doit bâtir son propre marché de l'énergie, un marché plus solidaire et régulé : car l'électricité n'est pas une marchandise comme les autres. Ce n'est pas un commerce ! C'est un bien public essentiel qui doit pouvoir bénéficier de politiques publiques et de soutiens (ou garanties) pour les investissements, et de cadres réglementaires incitatifs.…

Un marché se met en place sous l'impulsion des institutions de la CEDEAO avec la création du CEREEC (pour les EnR), d'un système d'échanges d'énergie électrique, d'une autorité de régulation régionale et du WAPP, mais les coopérations sont faibles et il y a encore trop peu d'interconnexion électrique dans la zone, malgré les efforts réels qui ont été rappelés.

Un pacte de solidarité régional entre les états, respectueux des atouts de chacun, favoriserait les projets de coopération en complémentarité et d'infrastructures communes (centrales de production, installations décentralisées, réseaux...), et mutualiserait les financements pour leur réalisation, et mobiliseraient les investisseurs. Ne faut-il pas également étendre les capacités de financement des banques publiques de développement et créer des fonds de solidarité abondés par le public et le privé ?

Comment valoriser les projets africains et attirer les investissements ? L'Afrique est sortie du face à face avec l'Europe. Les relations économiques et de « partenariats » sont enclenchées depuis 20 ans avec la Chine et depuis 10 ans avec l'Inde, le Brésil, la Turquie, l'Arabie Saoudite, ou même la Russie... En 2019, les USA aussi ont redéfini leurs politiques commerciale et d'« aide publique » avec l'Afrique. Le Maroc depuis 7 ans accélère ses relations avec l'Afrique subsaharienne et développe ses investissements. La question qui se pose pour l'Europe, c'est de changer de comportement, et de transformer les « aides au développement » pour en faire des aides à l'investissement pour financer des projets locaux et régionaux définis par les Africains eux-mêmes, et répondant à leurs besoins et à leurs demandes, financer les projets d'interconnexion transfrontières entre des grandes villes qui irrigueraient les villages, contribuer à la création d'établissements pour la formation des ouvriers, techniciens et ingénieurs dont l'industrie et le secteur énergétique en particulier ont besoin, et organiser une mobilité positive pour le transfert de technologies et des compétences. La Ministre du Bénin appelle au renforcement des partenariats dans l'éducation, la recherche et l'innovation, et j'ajoute des coopérations économiques et industrielles dans l'intérêt mutuel.

Paris le 8 novembre 2021

Claude Fischer Herzog

Mesures du débit de la rivière Mwogere au moulinet hydrométrique par la méthode des points de vitesse

Jean Bosco Niyonzima
Département Electromécanique
Université du Burundi
Bujumbura, Burundi
jean.bosco.niyonzima@ub.edu.bi

Patrick Hendrick
Département Aéro-Thermo-Mécanique
Université Libre de Bruxelles
Bruxelles, Belgique
patrick.hendrick@ulb.be

Abstract - Le Burundi comporte plusieurs petits cours d'eau pour lesquels aucune étude hydrologique complète n'a été faite. Notons que l'hydroélectricité est une source d'énergie renouvelable et disponible sur toute l'année. Une étude de mesure de débits été conduite au Burundi, sur le site de Ryamukona. Cette étude vise à présenter les résultats de mesures de débit réalisées au Burundi sur la rivière Mwogere pour l'année 2017. Le débit nominal mesuré est de l'ordre de 1,18 m^3/s, en utilisant la méthode des points de vitesse. Connaissant le débit nominal et la hauteur de chute brute de 12 m, mesurée à l'aide d'un GPS, cette étude a alors abouti à la définition du potentiel hydroélectrique du site de Ryamukona, un potentiel estimé à 82 kW environ.

Cet article est une version raccourcie d'une publication du 6 novembre 2020 dans la "Revue des énergies renouvelables" du "Renewable energies development center" d'Alger, Algérie, Vol 23, N°1

Mots clés: Petites rivières, mesure de débit, méthode des points réduits, potentiel hydroélectrique.

***Abstract*—Burundi has several small rivers for which no complete hydrological study has been made. It should also be noted that hydroelectricity is a renewable source of energy and available throughout the year. A study was then conducted in Burundi, on the Ryamukona site. This paper aims to present the results of flow measurements conducted on the Mwogere River in Burundi for the year 2107. By using the reduced points-method, the nominal measured flow rate is equal to 1.18 m^3/s. Based on the obtained nominal discharge and the head measured using a garmin GPS at Ryamukona site, the study resulted to the definition of the hydroelectric potential of the Ryamukona site. The hydroelectricity potential of the site is around 82 kW.**

This paper is a shortened version of a publication of November 6th 2020 in the "Journal of renewable energies" of the "Renewable energies development center" Algiers, Algeria, Vol 23, N°1.

Keywords— Small rivers, flow measurement, reduced-points method, hydroelectricity potentia

I. INTRODUCTION

Avec le risque d'épuisement des sources d'énergies fossiles, le potentiel hydroélectrique constitue une solution incontournable pour la production d'énergie dans le monde. Or, l'exploitation de l'hydroélectricité, qui est une source d'énergie renouvelable, nécessite des études hydrologiques détaillées préalables des cours d'eau. La revue de la littérature au Burundi fait état de deux grandes études menées sur le potentiel hydroélectrique du pays. Selon l'étude réalisée par Lahmeyer en 1983 [1], le Burundi a un potentiel hydroélectrique important avec 1731 sites pour lesquels une capacité de 294 MW est techniquement et économiquement exploitable. L'étude la plus récente est celle réalisée par Sher ingénieurs conseils, et cette dernière a identifié un potentiel hydroélectrique un peu plus élevé de 414 MW dont une capacité hydroélectrique de 194 MW peut être exploitée en priorité [1]. Néanmoins, ces deux études présentent une certaine faiblesse par le fait que les mesures de débit ont été réalisées de façon ponctuelle sur une courte durée. Des mesures de débit fiables pour les petites rivières non jaugées nécessitent en effet que les mesures soient faites sur une période d'une année au minimum [2].

Le Burundi comprend plusieurs petits cours d'eau, comme la rivière Mwogere, qui ont un potentiel hydroélectrique important et amène l'électricité verte aux populations rurales. Le comportement hydrologique de ces cours d'eau varie en fonction des saisons au cours de l'année. Au Burundi, il y a deux grandes saisons, la saison sèche et la saison pluvieuse. La rivière Mwogere est une petite rivière non jaugée ne disposant d'aucune donnée de débit. L'objectif de cette étude est de présenter les résultats d'une campagne de mesures de débit réalisées sur la rivière Mwogere pour toute l'année 2017. La revue de littérature montre que, depuis 1960, plusieurs études sur la méthode de mesure de débit des cours d'eau ont été faites [3, 4, 5, 6]. On remarque que la méthode d'exploration des champs de vitesse et la méthode de dilution d'un traceur chimique sont les plus utilisées. Le choix de la méthode à utiliser doit évidemment prendre en considération les conditions d'écoulement de la rivière. La méthode de la mesure de débit dite « des points de vitesse », aussi appelée méthode des points réduits, requiert un écoulement non perturbé alors que, pour la méthode de dilution d'un traceur chimique, la perturbation de l'écoulement est l'un des facteurs favorables pour sa bonne utilisation. Dans le cas de la rivière Mwogere, la mesure de débit a été réalisée en utilisant la méthode des points réduits. Cette méthode est facile à utiliser par les opérateurs et l'utilisation de l'instrument de mesure ne demande pas un gros niveau de formation préalable. La méthode de dilution de traceur est, quant à elle, difficile à appliquer et elle exige beaucoup d'attention et un certain niveau de formation. Les mesures de débit du site de Ryamukona ont été effectuées deux fois par mois et les débits mensuels obtenus ont été utilisés pour la construction de la courbe des débits instantanés. La courbe de débits instantanés pour le site de Ryamukona est une courbe qui représente les débits mensuels de la rivière Mwogere en fonction des mois de l'année 2017. La courbe de débits classés est tracée par la suite, en réorganisant les débits instantanés de la rivière par ordre décroissant. La courbe de débits classés est un outil utilisé pour la détermination des débits caractéristiques de la rivière Mwogere : le débit nominal, le débit minimal, le débit réservé et le débit turbinable. Le débit nominal de la rivière Mwogere est de l'ordre de 1,18 m3/s. La valeur du débit nominal est capitale pour la sélection de la turbine hydraulique adaptée pour un site donné. Connaissant le débit nominal et la hauteur de chute du site de Ryamukona, une étude du potentiel hydroélectrique a été réalisée dans le but d'estimer la puissance électrique d'une microcentrale hydroélectrique projetée pour ce site. La colline de Ryamukona constitue une zone d'extraction de minerai de coltan. Le traitement du coltan requiert un lavage du minerai et l'eau de lavage de ce minerai est ensuite déversée dans la rivière Mwogere, ce qui fait que les travaux d'extraction des restes de coltan sont effectués tous les jours dans la rivière Mwogere par les paysans des collines voisines à la rivière Mwogere. Ces travaux d'extraction dans la rivière Mwogere ont donc des conséquences néfastes pour l'écoulement de la rivière. Hormis l'introduction et la conclusion, cette étude a développé trois parties principales. La première partie et la deuxième partie présentent la méthode utilisée pour les mesures de débits, les résultats des mesures et la discussion de ces résultats. La troisième partie de cette étude porte sur l'étude du potentiel hydroélectrique.

II. METHODES ET OBSERVATIONS

III. Localisation du site

La rivière Mwogere se trouve dans la commune de Kabarore de la province de Kayanza au nord du Burundi. Le tronçon de mesure de débit s'étend sur une longueur de 500 m environ, mesurée à l'aide d'un GPSMAP 64s. La Figure 1 est une illustration de la localisation du tronçon sur la rivière Mwogere par rapport au site d'extraction de coltan situé sur la colline de Ryamukona. Le tronçon est délimité par la ligne jaune sur la carte et se trouve à 800 m environ du chef-lieu de la colline Runyinya. Le site d'extraction du coltan se situe sur la colline de Ryamukona, à 800 m environ. D'autres sites d'extraction de coltan sont situés sur les autres collines voisines du site.

Fig. 1. Localisation et délimitation de la section de mesure de débit

IV. Mesure de débit au moulinet Flowatch

Dans le cadre de la rivière Mwogere, des mesures de débit ont été faites sur une période d'une année complète qui couvre donc les deux grandes saisons de l'année: saison pluvieuse et saison sèche. La mesure de débit est faite en mesurant la vitesse d'écoulement de l'eau sur des verticales dans le lit de la rivière, ce qui conduit par conséquent au calcul de débit partiel associé à chaque verticale. La mesure de la vitesse a été faite en utilisant un moulinet hydrométrique. La méthode de mesure de vitesse utilisée est la méthode dite des « points de vitesse ». La méthode des points de vitesse consiste à choisir un certain nombre de verticales sur la section transversale sur laquelle la mesure de débit sera faite, et d'effectuer les mesures de vitesse d'écoulement sur uncertain nombre de points de chaque verticale et on calcule la vitesse moyenne associée à chaque verticale [4, 5, 6, 7].

Dans le cas du site de Raymukona, les mesures ont été faites sur une période de 12 mois de janvier à décembre 2017 et deux mesures par mois ont été prises par une équipe d'opérateurs formés au préalable. Avant de commencer les mesures, l'opérateur procède à la délimitation de la largeur de la section sur laquelle il va mesurer le débit de l'eau et il repère par la suite un certain nombre de verticales sur lesquelles il effectue les mesures de débit. Le nombre de verticales sur la section de mesure dépend de la largeur de la rivière [5]. Le Tableau 1 montre que la largeur b de la section de mesure est supérieure à 6 m, le nombre de verticale peut être de l'ordre de 12 et plus.

Après la délimitation de la section de mesure, on mesure d'abord la profondeur sur chaque verticale et cette profondeur permet à l'opérateur de déterminer le nombre de points de mesure sur la verticale considérée [7]. C'est la profondeur de l'eau sur chaque verticale qui va déterminer le nombre de points de mesure de la vitesse de l'eau. La Figure 2 montre que la vitesse de l'eau est plus grande à la surface de l'eau par rapport à la vitesse de l'eau au fond de la rivière. Dans le cas où la profondeur de la verticale est inférieure ou égale à 0,25 m, une seule mesure de vitesse d'écoulement est requise. En désignant par P la profondeur de chaque verticale, l'opérateur effectue une mesure de vitesse à 0,6 fois la profondeur P de la verticale en-dessous de la surface de l'eau. Dans le cas où la profondeur de la rivière est supérieure à 0,25 m, deux mesures de vitesse sont faites, respectivement à 0,2 P et à 0,8 P de la verticale en-dessous de la surface de l'eau. Le calcul de débit sur chaque verticale considère une moyenne des mesures de vitesse effectuées. Les mesures de vitesse de l'eau sur la rivière Mwogere sont réalisées soit en un point soit en deux points de chaque verticale

TABLE I. NOMBRE DE VERTICALES [7]

Largeur de la rivière	Nombre de verticales
b < 0,5 m	3
b < 0,5 m < 1,0 m	4 à 5
1,0 m < b < 3,0 m	5 à 8
3,0 m < b < 6,0 m	8 à 12
b > 6,0 m	12 et plus

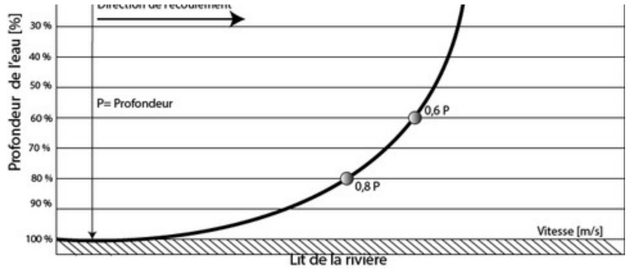

Fig. 2. Profil des vitesses chaque verticale

V. *Calcul de débit*

La méthode de « section médiane » a été appliquée pour la détermination du débit élémentaire associé à chaque verticale dans le cadre des mesures de débit avec le courantomètre moulinet [7, 8, 6, 9]. En se basant sur l'illustration de la Figure 3, une section médiane est un segment rectangulaire s'étalant entre deux verticales situées respectivement en amont et en aval de la verticale considérée. On prend alors la vitesse moyenne des vitesses mesurées sur chaque verticale de la section considérée et le débit élémentaire sur chaque verticale est calculé en utilisant la formule de l'Eq.(1). Selon la Figure 3, la section médiane est représentée par les lignes en pointillés rouges et les verticales sont numérotées de 0 à n, le débit partiel est q en m^3/s, la profondeur d en m et la distance b en m qui est la distance entre le point de référence et la verticale considérée. Les indices i-1 et i+1 expriment respectivement la verticale qui précède et qui suit la verticale i considérée. Pour les verticales situées au début et à la fin de la section, la méthode considère que la première et la dernière verticale coïncident respectivement avec la précédente et la suivante de la verticale considérée. Le débit sur les verticales est alors calculé en utilisant les formules des Eqs.(1, 2 et 3). Le débit global sur la section de mesure est la somme des débits élémentaires correspondants à chaque verticale et il est déterminé à l'aide de la formule de l'Eq.(4). Les résultats de débit servent à la construction de deux courbes : la courbe de débits instantanés la courbe des débits classés. La courbe de débits classés joue un rôle important dans la détermination du comportement hydrologique d'une rivière donnée.

En vue de garantir la vie, la circulation et la reproduction des espèces piscicoles dans la rivière, un débit de maintien à l'aval de la rivière doit être suffisant selon la norme Suisse [10, 11]. Ce débit est appelé débit de restitution ou débit réservé. Le débit réservé Qres est par définition le débit qui doit être maintenu dans le tronçon de la rivière entre la prise d'eau et la centrale. Il est égal au produit entre le débit minimal de la rivière et un constante de tranche de débit Rq [11]. Le débit minimum est le débit atteint ou dépassé pendant une durée de 347 jours sur l'année [12]. Le coefficient Rq de tranche de débit est calculé en fonction des tranches de débit minimum [10, 13]: pour un débit minimum compris entre 2500 l/s et 900 l/s, Rq=21,3 %. Connaissant le débit minimal et le coefficient Rq, le débit réservé est calculé selon la formule de l'Eq.(5). Le débit turbinable alors égal à la différence entre le débit nominal et le débit réservé.

$$q_i = v_i\left(\frac{b_i - b_{(i-1)}}{2} + \frac{b_{(i+1)} - b_i}{2}\right) d_i$$
$$v_i\left(\frac{b_{(i+1)} - b_{(i-1)}}{2}\right) d_i \quad (1)$$

$$q_1 = v_1\left(\frac{b_2 - b_1}{2}\right) d_1 \quad (2)$$

$$q_n = v_n\left(\frac{b_n - b_{(n-1)}}{2}\right) d_n \quad (3)$$

$$Q = q_1 + q_2 + q_3 + \ldots + q_{n-1} + q_n \quad (4)$$

$$Q_{res} = Rq * Q_{min} \quad (5)$$

Le calcul de débit en utilisant la méthode des points de vitesse est accompagné par des erreurs qu'il faut évaluer en vue d'avoir une vraie grandeur de la valeur mesurée. La norme ISO 748 (2007) propose une méthode d'évaluation des incertitudes [14]. Une étude menée par Lecoz et al. (2014) [15] a montré que l'évaluation de cette incertitude tient compte de plusieurs paramètres, à savoir, la méthode de mesure utilisée, la profondeur de la rivière, la largeur de rivière, l'appareil de mesure, etc. La formule de l'Eq.(6) a été utilisée pour l'analyse de l'erreur des mesures de débit effectuées sur la rivière Mwogere.

$$u(Q) = \quad (6)$$

u(Q) représente l'incertitude relative en %, m, i, n: nombre de verticales, $i^{ème}$ verticale, nombre de points de mesure en profondeur, b, d, $\bar{v}$: largeur, profondeur et vitesse moyenne sur chaque verticale, u^m: incertitude relative liée au nombre limité de verticales, u_s: incertitude relative liée au calibrage de l'appareil de mesure de vitesse, de largeur et de profondeur, u_b et u_d: incertitude relative liée aux erreurs aléatoires de mesure de la largeur et de la profondeur, u_p: incertitude relative liée à la vitesse moyenne due au nombre limité de points de mesure, u_c: incertitude relative de la vitesse en profondeur due à la prise unique de vitesse, u_e: incertitude relative de la vitesse en profondeur due à la fluctuation de vitesse. L'incertitude relative u(Q) est alors de l'ordre de 3,3 %.

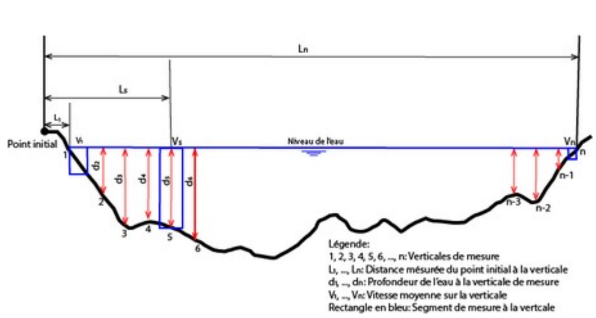

Fig. 3. Principe de la méthode de la section-médiane [7]

VI. *Turbines hydrauliques*

Parmi les autres sources d'énergie renouvelable, l'hydroélectricité constitue la source d'énergie renouvelable la plus exploitée. Dans un projet d'hydroélectricité, la valeur du débit nominal mesuré et caractérisant une rivière a une importance capitale dans le dimensionnement d'une machine hydraulique adaptée à un site donné, pour l'estimation du coût de l'équipement et du génie civil et pour le calcul de la quantité d'énergie à produire.

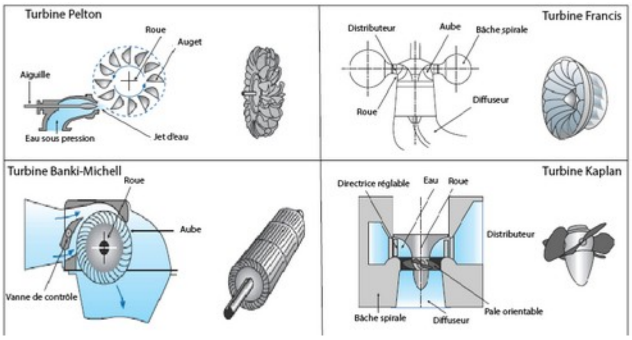

Fig. 4. Type de turbines hydrauliques [16]

La Figure 4 illustre les principaux types de turbines hydrauliques. Elles peuvent être groupées en deux grandes catégories, à savoir, les turbines à action appelées aussi turbines à impulsion et les turbines à réaction. Dans la catégorie des turbines à action, l'énergie de l'eau à la sortie de l'injecteur ou du distributeur est entièrement sous forme d'énergie cinétique et l'eau à cet endroit se trouve à pression atmosphérique. On dit que la turbine à action tourne en partie dans l'air [11] et le transfert de l'énergie au niveau du rotor se fait à pression atmosphérique. Dans cette catégorie de turbines, on trouve la turbine Pelton, la Turgo et la Banki-Michell. Dans le cas des turbines à réaction, le rotor de la turbine est complètement noyé dans l'eau et l'énergie à la sortie du distributeur se trouve à la fois sous forme de pression et d'énergie cinétique [12]. La pression de l'eau est donc ici supérieure à la pression atmosphérique.

La force de l'eau va provoquer une force hydrodynamique sur le profil de l'aubage, ce qui induit un couple sur l'arbre de la turbine. La force portante est le résultat d'une différence de pression sur les deux faces de l'aubage (intrados et extrados) qui va forcer le rotor à tourner. La pression de l'eau à la sortie du rotor est inférieure à la pression siégeant à l'entrée du rotor. La catégorie des turbines hydrauliques à réaction comporte principalement les turbines Francis et Kaplan. Hormis les conditions topographiques du site, la sélection d'un type de turbine adaptée pour la production hydroélectrique d'un site donné va être fonction à la fois du débit nominal mesuré de la rivière et de la hauteur de chute du site.

VII. Présentation et discussion des résultats

Les mesures de largeur, de profondeur de la rivière et de vitesse de l'eau sont compilées dans une feuille de calcul Excel et des calculs de débit sont effectués en utilisant les formules des Eq. (2, 3 et 4). Le Tableau 2 présente un exemple de feuille de calcul pour le traitement des mesures de débit réalisées le 23 novembre 2017.

TABLE II. RESULTATS DE MESURE DE DÉBIT OBTENUS LE 23//11/2017

Nom du site: Ryamukona
Date: 23/11/2017
Heure: 10h05 à 10h26
Largeur (m): 13.50

Numéro de verticales	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
Largeur (m)	0	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	
Profondeur P (m)	0.14	0.2	0.28	0.28	0.29	0.24	0.2	0.17	0.13	0.14	0.14	0.14	0.13	0.13	0.14	0.14	0.13	0.12	0.12	
Vitesse en 0,2P (m/s)			2.6	2.6	2.7															
Vitesse en 0,6P (m/s)	0.6	0.7				2.4	1.9	2.3	2.3	2.4	2.2	2.2	2	2.3	2.4	2.2	1.6	1.9	1.4	
Vitesse en 0,8P (m/s)			2.3	2.3	2.3															
Vitesse moyenne (m/s)	0.6	0.7	2.45	2.45	2.5	2.4	1.9	2.3	2.3	2.4	2.2	2.2	2	2.3	2.4	2.2	1.6	1.9	1.4	2.0
Aire (m^2)	0.03	0.08	0.11	0.11	0.12	0.1	0.08	0.07	0.05	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.05	0.02	1.25
Débit (m^3/s)	0.02	0.06	0.27	0.27	0.29	0.23	0.15	0.16	0.12	0.13	0.12	0.12	0.1	0.12	0.13	0.12	0.08	0.09	0.03	2.64
Température (°C)	20.7	20.3	19.8	19.6	19.5	19.5	19.4	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.8	19.8	19.8	19.8	19.7

Selon le Tableau 2, les mesures de vitesse de l'eau sont faites soit en un point soit en deux points de la verticale selon la profondeur de verticale et on calcule la vitesse moyenne correspondante à chaque verticale. Le débit élémentaire est alors calculé selon les formules 2, 3 et 4. Le débit total obtenu pour cette date est de 2,64 m^3/s. En plus de la mesure de débit, l'instrument de mesure utilisé peut aussi mesurer la température de l'eau de la rivière au moment de la séance de mesure de débit. Les mesures faites pour la température donnent une moyenne de température de la rivière de 19,7 °C pour cette date. Les résultats obtenus de la profondeur de la rivière en-dessous de la surface de l'eau ont été étudiés pour analyser la variabilité du fond de la rivière. Le profil de la section transversale consiste à représenter la profondeur de l'eau du cours d'eau en fonction de la largeur de section de mesure. La Figure 5 représente deux profils différents pour la même section transversale sur laquelle les mesures de débit ont été faites. Ces deux séances de mesure de débit étaient espacées de 1h14 min. La profondeur de l'eau de la rivière a considérablement varié en fonction du temps. Ce changement de profondeur est causé par la mobilité du gravier et du sable dans la rivière. La berge droite de la rivière présente une zone morte due à la végétation sur le bord de la rivière. La vitesse de l'écoulement de l'eau est quasiment nulle dans la zone, dite morte, d'un cours d'eau

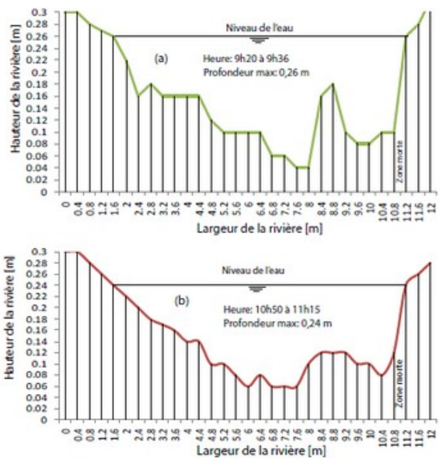

Fig. 5. Profil de la section transversale de la mesure de débit

Les résultats de débits ont permis la construction de deux courbes caractéristiques pour la rivière Mwogere : la courbe de débits instantanés et la courbe de débits classés. La courbe des débits instantanés de la Figure 6 a été tracée en utilisant les débits mensuels obtenus au terme de la campagne de mesures de débit pour l'année 2017.

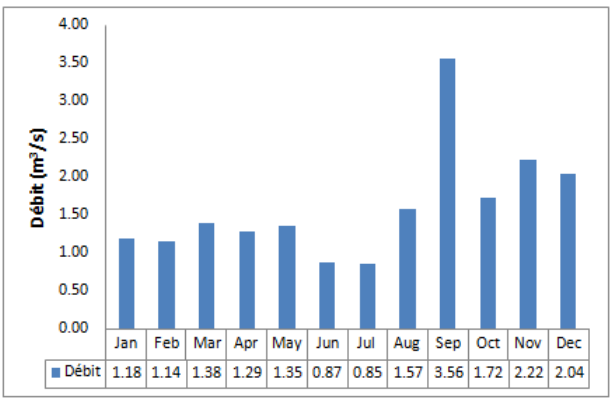

Fig. 6. Evolution des débits instantanés

Les résultats du mois de septembre présentent une certaine surestimation qui a été causée par une panne technique de l'instrument de mesure utilisé. Toutefois, cette erreur de mesure a été minimisée en moyennant les deux mesures faites pour le mois considéré. La courbe de débits classés de la Figure 7 représente les débits de la rivière atteints ou dépassés sur un pourcentage donné de temps sur toute l'année. Cette courbe de débits classés a été établie en réorganisant par ordre décroissant les débits mensuels et en représentant les débits ainsi obtenus en fonction du pourcentage de temps pour l'année 2017. Cette courbe de débits classés a permis de déterminer les débits caractéristiques de la rivière Mwogere: le débit nominal, le débit minimum, le débit réservé et le débit turbinable. Le débit nominal et le débit turbinable permettent de caractériser la turbine hydraulique adaptée pour le site Ryamukona. Le débit nominal du site de Ryamukona représente donc le débit atteint ou dépassé sur 75 % de l'année 2017 [11]. Selon l'Eq.(5), le débit réservé est égal au produit du débit nominal par un coefficient Rq. Le débit minimal de la rivière Mwogere est alors égal au débit atteint ou dépassé sur 95 % de l'année. Selon la courbe de débits classés de la rivière Mwogere pour l'année 2017, l'abscisse 95 % est une valeur comprise dans l'intervalle [91,5 %, 100 %]. Le débit minimal est donc de 0,85 m^3/s. Dans le cas de la rivière Mwogere, le coefficient Rq est de 0,213, ce qui donne un débit réservé de 0,18 m^3/s. Le débit turbinable est donc de 1,0 m^3/s. Par définition, le débit turbinable est le débit turbiné en-dessous duquel on doit arrêter la turbine hydraulique.

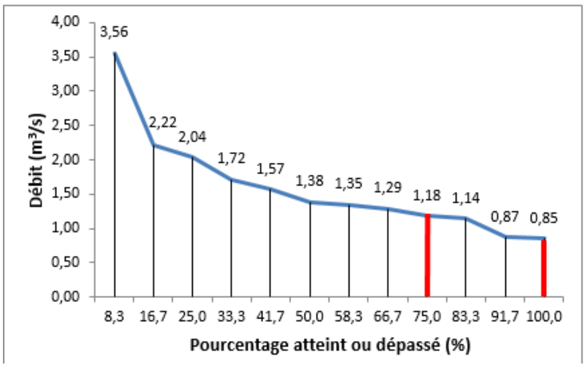

Fig. 7. Courbe de débits classés pour l'année 2017

VIII. Potentiel hydroelectrique du site de Ryamukona

La puissance hydraulique à disposition d'une turbine dans un aménagement hydroélectrique est donnée par la relation de l'Eq.(7), dans laquelle P_h est la puissance hydraulique en W, ρ est la masse volumique en kg/m^3, Q est le débit en m^3/s, g en m/s^2 est l'accélération de la pesanteur et H en m est la hauteur de chute. La puissance électrique d'une petite centrale hydroélectrique projetée sur un site peut alors être calculée par la formule de l'Eq.(8). Cette estimation de puissance électrique $P_{él}$ est calculée en fonction de la puissance fournie par l'eau en considérant un rendement global η_G de 70%. Ce rendement tient compte des pertes et du rendement de la turbine, du générateur et de la transmission [16]. Cela signifie que seules 70% de la puissance hydraulique sont transformés en énergie électrique et utilisables par la population locale.

IX. *Détermination du potentiel hydroélectrique*

Dans le cas du site de Ryamukona, le débit Q est égal au débit turbinable présenté au paragraphe 3, soit Q = 1,0 m^3/s. La hauteur de chute H est définie comme étant la différence entre l'altitude du plan d'eau amont à la prise d'eau et l'altitude du plan d'eau aval pour les turbines à réaction, et pour les turbines à action, elle est définie comme étant la différence entre l'altitude du plan d'eau amont à la prise d'eau et le niveau de l'axe de la roue [2]. Dans le cas du site de Ryamukona, la mesure de hauteur de chute brute a été mesurée à l'aide d'un appareil GPSMAP 64s et la hauteur de chute mesurée est de 12,0 m. Connaissant le débit Q et la hauteur de chute brute, on a pu définir le type d'aménagement hydroélectrique adapté pour le site de Ryamukona. La carte de la Figure 8 est une illustration schématique du type d'aménagement hydroélectrique du site de Ryamukona sur lequel ont été géolocalisés la prise d'eau, la chambre de mise en charge et la centrale hydroélectrique.

$$P_h = \rho.Q.g.H \qquad (7)$$

$$P_{él} = 0,70.P_h \qquad (8)$$

En fonction de la topographie du site, l'aménagement hydroélectrique possible pour le site de Ryamukona est de type « au fil de l'eau ». L'eau est alors déviée à travers un canal de dérivation d'environ 290 m qui s'étend entre la prise d'eau (1) et la chambre de mise en charge (3). L'eau est, par la suite, mise à grande vitesse d'écoulement et dirigée vers la turbine à travers une conduite forcée. La prise d'eau est localisée sur la rivière Mwogere à une altitude de 1732 m, à une latitude de -2,82184444° et à 29,6000472° de longitude ouest. Le potentiel hydroélectrique du site de Ryamukona donne alors une capacité en puissance de 82 kW. Il faut remarquer que la population du Burundi est dominée par une population rurale à ± 90%, et la majeure partie des zones rurales est localisée loin du réseau électrique national [19]. Dans ce cas, l'hydroélectricité permet de fournir de l'électricité propre à la population des zones rurales isolées du réseau électrique.

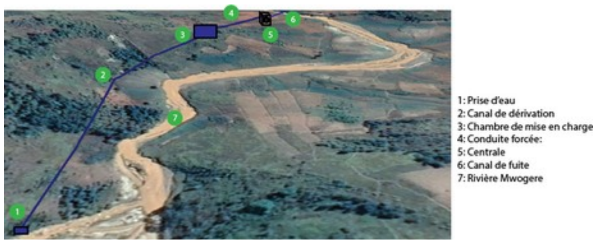

Fig. 8. Schéma d'une microcentrale hydroélectrique

X. *Prévision de la charge électrique*

En connaissant le potentiel hydroélectrique du site de Ryamukona, une étude a été réalisée dans l'optique de déterminer la charge électrique prévue pour ce site sur une échelle d'une journée. La prévision de la demande de l'électricité a été faite en considérant une estimation de 100 ménages regroupés sur les chefs-lieux des collines Ryamukona, Kibuba, Kivumu, Runyinya, Karama et Mutana. Les secteurs de consommation identifiés sur ces collines sont les ménages, les boutiques pour des petits commerces, les petites cafétérias, les écoles fondamentales, les centres de santé, les moulins à céréales et manioc, les églises, etc.

La courbe de charge électrique est donc une représentation de la puissance maximale demandée sur un intervalle de temps d'une journée. La courbe de la charge électrique de la Figure 12 permettra alors de faire ressortir la puissance maximale à atteindre pour le site de Ryamukona à des moments précis de la journée. La période allant de 6h00 à 8h00 du matin correspond au moment où les personnes se préparent pour aller vaquer aux différentes activités quotidiennes. La puissance maximale demandée pendant cette période est de 51,50 kW. La période allant de 16h00 à 23h00 constitue la période pendant laquelle plusieurs activités sont réalisées : éclairage des maisons, utilisation des postes de télévision, les activités dans les salons de coiffure, etc. La puissance maximale demandée pour la période allant de 18h00 à 21h00 est de 81,84 kW. La courbe de la charge électrique prévue pour le site de Ryamukona montre que la puissance électrique appelée sur une échelle journalière ne dépasse normalement jamais la puissance électrique disponible de 82 kW.

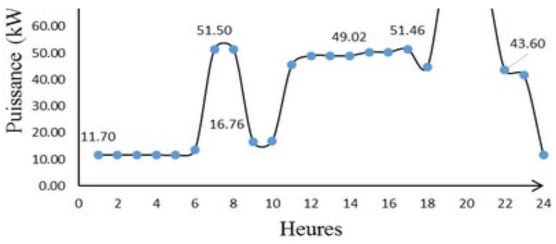

Fig. 9. Courbe de la charge électrique Ryamukona

XI. CONCLUSION

Le Burundi est un pays qui jouit d'un potentiel hydrologique important avec beaucoup de petits cours d'eau, qui n'ont malheureusement pas de données fiables sur les valeurs de débits. Les valeurs disponibles de débits sont exploitées dans la construction des microcentrales hydroélectriques pour les zones rurales, sachant que l'hydroélectricité est une source d'énergie renouvelable qui fournit à la population de l'électricité propre et fiable.

A travers cette étude, des mesures de débit ont été réalisées sur la rivière Mwogere, et les résultats de ces mesures ont donné une courbe de débits classés de la rivière Mwogere pour l'année 2017. Les résultats de cette étude pourront être utilisés par d'autres scientifiques ou par les autres acteurs dans le domaine de l'énergie du Burundi, pour des éventuelles études hydrologiques des autres petites rivières du potentiel hydroélectrique burundais. Le débit nominal mesuré est de l'ordre de 1,18 m^3/s. Connaissant le débit turbinable et la hauteur de chute brute qui caractérisent le site de Ryamukona, le potentiel hydroélectrique brut du site a été évalué à 82 kW. Avec une telle puissance hydroélectrique, les conditions socio-économiques de la population locale peuvent être améliorées en construisant une microcentrale hydroélectrique qui peut fournir de l'électricité verte à environ 600 ménages, à quelques boutiques de petits commerces, à de petites cafétérias, à des écoles fondamentales, à des centres de santé, etc. Cela améliorera les conditions de vie d'une grande partie de la population de cette zone.

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Pay as you go companies are game-changers in Africa by making energy affordable : the case of Chad

Youssouf Ali Mbodou

Kouran Jabo

N'Djamena, Chad.

youssouf@kouranjabo.com

***Abstract*—This article describes how to use the pay as you go technology is making energy accessible and affordable for low-income families in rural and semi urban area.**

***Index Terms*—pay as you go, solar energy, electrification, Chad**

Kouran Jabo is a social start-up making energy accessible and affordable through solar energy. Our vision is to enable every Chadian to have access to clean and affordable energy using a Pay as you go model.

Within the past years, Sub-Saharan Africa has witnessed incredible growth in the use of pico-scale solar PV products by private consumers. Sales have expanded from less than 100,000 units per year in 2010 to more than 4 million units in 2014 according to Bloomberg off grid report 2016[13], with forecasts expecting further growth in the future. The development has been particularly pronounced in Kenya, Ethiopia and Tanzania, but other countries are also picking up.

In Kenya, more than 30 percent of people living off the grid have a solar product at home, the pioneers have helped to create a vibrant market.

Off-grid solar is advancing rapidly beyond just lighting and phone charging, between cost reductions, latent consumer demand and a sales-driven push for higher-margin products, solar home systems capable of powering appliances such as TVs and fans are likely to capture an increasing market share. About 7 million off-grid households will use solar-powered fans and 15 million households will have a solar-powered TV, according to Off-Grid Solar Market Trends Report 2016.

In Chad, access to electricity is still a major problem according to world bank[14] only 10% of the population in Chad has access to electricity. There is no interconnected network in the country. The country electricity rate ranks it second to the last in the world, the urban area is 16% electrified meanwhile the rural area is only 1% electrified.

Today, due to the lack of access to electricity, citizens resort to expensive, polluting and sometimes alternatives dangerous to their health. However, Chad has an invaluable, inexhaustible and accessible resource: one of the highest levels of sunshine in the world. Kouran Jabo's vision is to provide solutions to improve the lives of low-income people by giving them access to modern, clean energy: solar energy.

Our added value is based on innovation: with the Internet of Things (IoT) and the Pay As You Go technology integrated into our solar devices, we offer the poorest households affordable prices, adapted to their means, and giving them access to reliable energy.

Chad represents a potential 90,000,000 million euro with, to date, more than 90% of the population without access to electricity and without any real competition in the market.

We estimate the Central Africa represents a potential of 2,5 billion euro with more than 125 million people without access to energy.

[13] https://about.bnef.com/blog/off-grid-solar-market-trends-report-2016/
[14] https://donnees.banquemondiale.org/indicateur/EG.ELC.ACCS.ZS

Renewable energy and productive water for irrigation purposes in the provinces of Manica, Zambezia and Sofala (Mozambique)

Mark Hoekstra
Intervention Manager
Renewable Energy for Rural Development
ENABEL
Maputo, Mozambique
mark.hoekstra@enabel.be

Sophie Bénédicte Jacques
Energy Expert
ENABEL
Brussels, Belgium
benedicte.jacques@enabel.be

***Abstract*— In the present context of climate change, current farming systems of Mozambique will be highly affected in the near future if appropriate irrigation and agricultural practices, based on sustainable production and climate resilience, are not developed. Enabel foresees the development of about 1,000 solar-powered irrigation installations on 900 ha of - irrigated - agricultural land with 1,010 farmers applying the best irrigation and agronomic practices. By promoting Solar Powered Irrigation Systems (SPIS), our intervention highlights the need of a multi-sectoral approach and an inter-sectoral coordination between sectors.**

Keywords—access to energy, productive use of energy, productive water use, solar pumping & irrigation, rural development

I. Context

Mozambique is one of the poorest countries in the world with most of the population living in rural setting [15]. Poverty concerns over half of the population and is even more concentrated in rural areas.

On 3 April 2020, the Mozambican Parliament approved the new 5-year Government Plan 2020-2025 (PQG), which will guide government's intervention across all sectors for the next 5 years. The central objective of the plan is the diversification and competitiveness of the economy, as a lever for employment creation and income generation, in particular for the youth. This is to be achieved through a set of 3 priorities: (i) the promotion of human capital and social justice; (ii) boosting economic growth, productivity and job creation; and (iii) strengthening the sustainable management of natural resources and the environment.

Irrigation expansion is clearly specified as a way to support economic development; and renewable energies are highlighted as an essential resource for rural electrification taking into account the climatic challenges.

The Green Growth Potential Assessment (GGPA) carried out in 2018 [1], identified five priorities for green growth in Mozambique and focus on rural development.

Three of these priorities could be described as technical or economic challenges

- Improve agricultural productivity,
- Support renewable energy to improve rural livelihoods, and
- Reduce the depletion of natural resources (including forests, water, fish stocks, etc.).

According to the Global Climate Risk Index for 1999–2018 [2], Mozambique is the country most affected in Africa by climatic events [[16]] after Madagascar. Flooding, cyclones and severe drought events interfere with food, water and livelihood security systems. In the present context of climate change, notably with temperature rise that will affect crop yields, current farming systems of Mozambique will be highly affected in the near future if appropriate irrigation and agricultural practices, based on sustainable production and climate resilience, are not developed.

Although irrigation is specifically mentioned in governmental plans and strategies, most installed water pumping systems aimed to contribute water access for domestic use, whereas irrigation additionally will increase income-enhancing opportunities.

II. Program/project details and background

Our interventions in Mozambique are part of The Renewable Energy for Rural Development (RERD) program started on September 2010.

The RERD1 (2010-2016) first phase focused on installations of photovoltaic systems in schools, health centers and administrative buildings. The second phase RERD2 (2018-2024) renewable energy component of 12M€ and the recently added RERD2+ irrigation component of 10M€, build on RERD1 outcomes and lessons learned, concluded with a list of recommendations among which an increased attention to Productive uses of energy as well as development of small hydro and solar mini-grids and water pumping systems, with a focus on the irrigation sector.

Enabel foresees the development of about 1,000 solar-powered irrigation installations on 900 ha of - irrigated – agricultural land in the provinces of Manica and Zambezia with 1,010 farmers at applying the best irrigation and agronomic practices.

The choice of those provinces is linked to :

[15] Ranked 180 out of 188 countries on HDI (UNDP, 2018) with a total population of the country estimated at 29 million (2017) of which 76 % is rural

[16] with the 14th place in the world during this period

- former presence of Enabel (RERD1 and RERD2 projects)
- potential for SPIS uptake and agro-ecological conditions for irrigation
- availability of pre-feasibility studies developed by FUNAE in collaboration with GGGI (Manica) and GGGI/Enabel (Zambezia)
- And, are densely populated provinces.

III. A MULTI-SECTORAL APPROACH & INTER-SECTORAL COORDINATION

Promoting productive uses of renewable energy leveraging solar energy across the agricultural sector aims to provide livelihoods and income-enhancing opportunities for off-grid households/farmers.

By promoting Solar Powered Irrigation Systems (SPIS), our intervention covers 5 main sectors including energy, water, agriculture, environment /climate change and private sector development, highlighting the need of a multi-sectoral approach and an inter-sectoral coordination integrating the existing synergies, interactions but also conflicts and priorities between sectors.

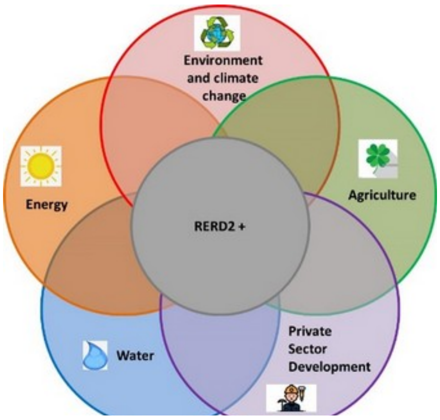

Fig. 1 Five main sectors for the intervention

The use of renewable energies for irrigation purposes integrates synergies between energy - water - food systems and represents ecosystems that are particularly vulnerable to climate change and essential for sustainable human development.

IV. SOLAR POWERED IRRIGATION SYSTEMS AND RECENT INNOVATIONS

In areas not connected to the grid, stand-alone solar PV

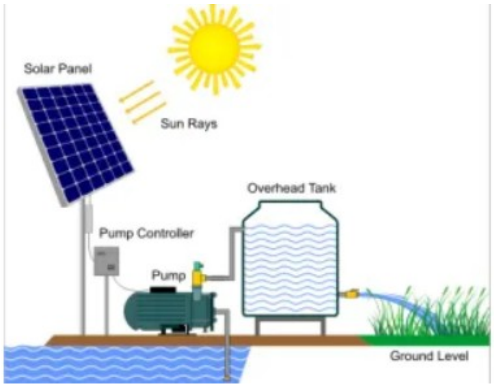

Fig 2 Illustration of a solar powered irrigation system

systems can be a reliable source of energy for pumping of irrigation water. Solar powered irrigation systems (SPIS) can help to stabilize, increase and diversify agricultural production, for example, vegetable production including during the dry season to complement staple crops.

The first solar-powered pumps were installed in the late 1970s but since 2009 the price of solar panels started to decrease significantly. Prices continue to drop and solar technologies are becoming a viable option for both large and small-scale farmers. Prices for pumps and controllers have also dropped although not important as the PV panels [[17]].

At the farm level, benefits of SPIS include independence from fuel prices and unreliable supply, low operational cost of pumping making it cheaper on the long run, potential increase in productivity and income, ...). At the national level, SPIS contributes to rural electrification, food security, job creation and overall rural development.

SPIS still requires relatively high initial investment, especially for smallholder farms, appropriate financing mechanisms, design to be fit-for-purpose (and thus depending on - private sector - services) and a certain degree of operations and maintenance technical knowledge. Determining the right choice of solar generator, pump type and size, as well as irrigation technology, is complex. The system has to be well adapted to the specific site conditions.

Solar pumping systems are continuously evolving and improving, including configurations with drip irrigation, floating solar panels or purely solar-driven centre-pivot irrigation machines. Electronic systems and software, have further increased performance and efficiency of SPIS. The key device is now the electronic controller, which adapts the available power from the solar generator to the solar pump.

V. MAIN CHALLENGES OF SOLAR POWERED IRRIGATION SYSTEMS

Solar powered irrigation systems (SPIS) can provide significant socio-economic and environmental benefits both at farm level and at national level. But SPIS is also facing a series of specific challenges in Mozambique. A summary of challenges as an outcome of SPIS SWOT analysis are presented in the table below:

[1] SPIS SWOT ANALYSIS

Strengths	Weaknesses
• Awareness among farmers about renewable energies (solar) • Strong needs manifested by farmers to diminish or even eliminate fossil energy costs • Awareness among farmers about the	• Relatively high prices for new solar equipment • Finance is not accessible or affordable for all, especially for smallholders • Lack of technological knowledge and technical skills

[17] Source: compilation, based on material from GIZ-FAO Toolbox on Solar-Powered Irrigation and Hartung H. & Lucie Pluschke (FAO, 2018), The benefits and risks of solar-powered irrigation - a global overview

immediately financial advantages in using SPIS • Availability of water resources in Manica and Zambezia	among farmers, suppliers and institutional partners at provincial level (no adequate extension systems, no adequate technical assistance, no adequate financing systems) • Low capacity of local suppliers regarding SPIS technology equipment and services • Lessons learned are not well disseminated • Land registration and rights remains a major hurdle
Opportunities	**Threats**
• Financing and cost of solar panels continue to drop, making SPIS economically viable and competitive with other sources of energy • Interest of users • Potential time saving due to replacement of labour intensive manual irrigation, which can lead to other income-generating activities. Women and/or children might profit from time not spent on watering anymore • Potentially more efficient use of water if combined with drip or other water- efficient irrigation technologies • Potential integration with sustainable agricultural practices such as agroforestry • Increasing number of Solar Systems Suppliers are entering the market and are slowly expanding operations to provi nces. • They may be willing to extend equipment on offer to SPIS systems • Presence of knowledge and training centers for education in the field of extension and engineering. • Approach promoted by the Government • Contribution to climate mitigation. Less pollution resulting from inadequate fuel handling (diesel pumps).	• Cross-sectoral themes, involving many actors and sectors. Decentralization not fully completed • Lack of harmonization and coordination between actors (public and private projects, donors, institutions) • SPIS vulnerable to theft • Lack of codes and standards to guarantee quality of SPIS • Climate change

VI. CONCLUSION

Successful irrigation projects highlight the need of :

At national/provincial level:

- an efficient combination of institutional and organizational arrangements,
- efficient coordination between different ministries or public entities (FUNAE, Ministry of Rural Development and Agriculture (MADER), Ministry of Public Works, Housing and Water Resources (MOPRH),
- strong institutional and technical actors
- adequate financing mechanism using a mix of public and private resources,

Fig. 5. sound design and technologies knowledge,

At local level:

- adequate extension systems, adequate technical assistance, adequate financing systems
- accessibility / affordability of solar equipment for all, especially for smallholders
- technological knowledge and technical skills among farmers and local suppliers regarding SPIS technology equipment and services

Multi-sectoral approach

Promoting Solar Powered Irrigation Systems tackles 5 inter-linked sectors: energy, water, agriculture, environment /climate change and private sector development. Integrating existing synergies, interactions but also conflicts and priorities between these sectors is key and highlights the need of a multi-sectoral approach and coordination.

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Electricity Access and Economic Development: The Case for Productive Use of Off-Grid Renewable Energy in Rural Africa

Susan Pendame,
Independent Researcher
Malawi
susanpendame2@yahoo.co.uk

***Abstract*—The aim of this paper is to give an overview of the off-grid renewable energy sector in Africa, to investigate the barriers to productive use of off grid renewable energy applications in rural areas and, following a review of literature, case studies and best practices, offer policy options that can be employed to realise the potential of productive use of renewable energy in aiding rural economic transformation in Africa.**

***Keywords*—Energy Access; Renewable Energy; Economic Growth; Productive Use of Off-Grid Renewable Energy.**

I. Introduction

Despite Africa's tremendous potential for renewable energy, an estimated 600 million people in Africa do not have access to electricity representing approximately two-thirds of the continent's population [1]

It is almost unanimously agreed that energy is crucial to economic development. Studies have shown a strong correlation between energy access and economic growth[2].

However, it is acknowledged that although energy access is necessary for economic development, is not sufficient by itself to trigger economic growth[3]. In order to spur economic growth, the use of energy has to be aligned in a way that will trigger economic growth through income generation for the people[4]. For that reason, there has been growing interest in Productive Use of Energy (PUE) and in particular of renewable energy (referred to as Productive Use of Renewable Energy or PURE), given the ability of off-grid renewable applications to reach millions who are not connected to the grid. PUE is considered a main priority for energy access in emerging countries particularly in rural settings[5].

There is no standardised definition of PUE and numerous varieties are used by practitioners. Several researchers and institutes have attempted to come up with their own definitions. Some of these definitions are derived directly from existing literature whilst others were drafted by the organisations or their donors. In their manual on Productive Use of Energy, GIZ (Deutsche Gesellschaft für Zusammenarbeit) and EUEI (European Union Energy Initiative) PDF (Partnership Dialogue Facility) define PUE as the "as agricultural, commercial and industrial activities involving electricity services as a direct input to the production of goods or provision of services"[6]. The Global Environment Facility (GEF) and UN Food and Agricultural Organization (FAO) define a productive use of energy as "one that involves the application of energy derived mainly from renewable resources to create goods and/or services either directly or indirectly for the production of income or value". Similarly, PURE has been defined as "agricultural, commercial and industrial activities, powered by renewable energy sources, which generate income"[6].

Traditionally PUE has been very narrowly defined. There has been quite a lot of debate as to what constitutes 'productive' as opposed to 'consumptive use' and the delineation is not clear cut. It is argued that many uses that are viewed as consumptive such as lighting and access to information (TV and the Internet) actually contribute to economic development. For example, it is suggested that children who have access to light, tv and internet have better educational outcomes that contribute to their future earnings. Whilst many practitioners acknowledge that there is a link between the uses that are often deemed consumptive and economic development, they point out that the linkages are less obvious and difficult, if not impossible, to quantify[3]. The varying definitions of PUE lead to different judgements by development practitioners on what to prioritise, implement and measure when carrying out PUE promotion projects[5]. For the purposes of this report, whilst not disregarding the long-term socio-economic gains of PUE, the report will adopt the narrower definitions of PUE that focus on income generation.

PUE can be employed at various levels of the value chain such as drip irrigation, refrigeration of food products, agro-processing and storage industries. The table I gives examples of productive applications of energy, their income generating values and possible energy sources. [4]

TABLE III. Productive uses of energy

Energy Services	Income Generating Value	Renewable Energy Services
irrigation	Better yields, higher value crops, greater reliability, growing during periods where the market prices are higher	Wind, PV solar, biomass, micro-hydro
illumination	Reading, extending operating hours	Wind, PV solar, biomass, micro-hydro,

		geothermal
grinding, milling, husking	Create value-added products from raw agricultural commodity	Wind, PV solar, biomass, micro-hydro
drying, smoking (preserving process heat)	Create value-added products, preserve product to enable selling in higher value markets	Biomass, solar heat, geothermal
expelling	Produce refined oil from seeds	Wind, PV solar, biomass, micro-hydro, geothermal
transport	Reaching markets	Biomass (biodiesel)
tv, radio, computer internet telephpone	Entertainment businesses, education, access to market news,coordination with suppliers and distributors	Wind, PV solar, biomass, micro-hydro, geothermal
battery charging	Wide range of services for end-users (phone charging business)	Wind, PV solar, biomass, micro-hydro, geothermal
refrigeration	Selling cooled products, increasing the durability of the products	Wind, PV solar, biomass, micro-hydro

Energy access and productive use of energy differ depending on the location of the users and the economic activities pursued. The upcoming sections discuss productive use of energy amongst amongst rural populations.

II. PRODUCTIVE VERSUS CONSUMPTIVE USE OF ENERGY

Electricity is often used for various consumption purposes such as lighting, access to information and entertainment which is not sufficient, in and of itself, to spur economic growth[7]. The usage of electricity needs to aligned in such a manner that it will spur economic growth through income generation activities of the local population [7]. There is therefore a need to move from consumptive use to productive use of electricity in order to realise the potential economic benefits of electricity access. Productive use activities in rural settings encompass local industries such as agriculture and fisheries, light manufacturing such as welding and carpentry and medium scale production such as agro-processing [8]. Productive use of renewable energy has the potential to transform rural economies and there is a particularly compelling case for productive use of renewable energy applications in agriculture given that the majority of rural African households depend on Agriculture for their livelihood [8]. In addition, productive use of renewable energy enables the diversification of the economic base by enabling the local community to deepen and move beyond conventional economic activities [7].

III. PRODUCTIVE USES OF ENERGY IN RURAL AREAS

Much attention has been paid to productive use of energy and rural development. Aside from raising rural incomes, modern energy services increase other informal aspects of rural incomes by reducing the amount of time spent on collecting firewood and dung used for energy generation in rural areas[9]. Much of the responsibility for collecting firewood falls disproportionately on women thus increasing access to modern energy services also increases gender equality. Further, access to modern energy facilitates the achievement of several of the MDGs in addition to gender equality including improving maternal health (through improved healthcare facilities which improvements often require electricity) and environmental sustainability as most projects that promote productive use of energy in rural areas emphasize the use of renewable energy. Based on market experience, productive use businesses in small villages often fall into one of the following categories [10]:

- Primary industries (e.g. agriculture, fishing, timber and livestock etc)
- Light manufacturing (e.g. carpentry, welding, icemaking etc)
- Commercial and retail enterprises (phone charging, eateries, grocers, hair salons, small freezers etc).

For many rural communities and especially those dependent on agriculture, the importance of looking at existing products, services and activities that originate in the community and then considering how value can be added through, or services created from, the supply of energy has been emphasized[10]. Similarly, it is also important to consider what products or services are imported into the area that could be produced or provided locally[10]. Further, interventions must take into account the business interests of local entrepreneurs and consider what resources entrepreneurs need to succeed in their local markets as well as what investments would be financially sound taking into account expected cashflows. This entails a thorough consideration of the local entrepreneurs' businesses, including the amount and quality of their products and services, the time spent on production and services, to revenues and costs (including energy costs), supply chain strategy, local access to markets, and market prices[10]. In this regard, participation of the local community in product use energy programmes and projects is crucial. There is need to have consultations with target groups to better understand the local needs. Consultations also increase the social acceptability of such programs[4].

Despite the availability of advanced renewable energy technologies and falling prices of such technologies, a number of barriers to the widespread adoption of renewable energy for productive use in rural areas remain. Rural populations are unable to invest capital up front. For several reasons, rural populations face severe problems in accessing credit and therefore have no means to meet this upfront cost. Women in particular are limited in their ability to access capital due to considerable gender biases often prevalent in rural areas. This limits their ability to be involved in productive uses of energy. Obtaining financing for small and medium-scale renewable energy projects has also remained difficult and the higher up-front cost of renewable energy installations can make such projects uncompetitive in comparison with diesel gensets.

Whilst many efforts have been undertaken to develop conducive policy and regulatory frameworks for renewable energy technologies, such frameworks are still inadequate. There is need to ensure level playing fields for renewable energy players. Other barriers that have been identified include lack of capacity building (particularly for women and the youth) including lack of training in the installation and operation of renewable energy technologies and lack of business and management training.

In order to unlock the potential for productive use of energy in rural areas, the barriers highlighted above would have to be addressed. It is crucial that further efforts are made to strengthen policy and regulatory environments for renewable energy by, for example, removing subsidies for fossil fuels, set up incentives such as feed-in-tariffs, transparent rules for becoming independent power producers and standardization of power purchase agreements. Further, activities related to the enabling environment such as training of government officials on productive use renewable energy technologies and benefits, advising on tariff setting for mini-grids, advising local government on how to adopt policies for productive use of energy promotion, supporting the development of quality standards and advising on tax and other relevant regulations should be considered.

Access to finance is critical to the scaling up and sustainability of projects and programs promoting PUE. In some instances, developers set up their own financing schemes such as concessionary loans or grants to bridge the access to finance gap. This may be done through direct financing to the enterprises/end-users or through local financial institutions or distribution companies/suppliers of appliances. Direct financing may be through pay as you go arrangements. It has been recognised that equipment/appliance financing is a critical component of enterprise development especially where capital costs of certain equipment and appliances can be high in comparison to the income of the enterprise. Therefore, an increasing number of energy service providers and project developers have realised that facilitating appliance uptake through provision of credit and appliance distribution is critical in increasing end-use energy demand in rural areas [11]. Therefore, energy generation is combined with a facility to purchase the equipment and/or appliances required to utilise the energy. Recent research conducted by the Minigrid innovation Lab found that the average income per customer increased steadily to 18 per cent above baseline levels 11 months after the introduction of provision of appliances indicating that making appliances available addresses the challenges of increasing electricity demand and productivity[12]. The demand for appliances is forecasted to increase as cost of productive equipment decreases. The business case for small businesses to invest in appliances especially through financing schemes offered by developers and energy suppliers is likely to improve. The table II demonstrates the power requirements, costs and indicative payback periods of selected productive use appliances in 2019.

Creating sustainable revenue models to cater to serve communities is a key challenge for the microgrid sector which sector is critical to productive use of energy in rural areas[11]. Growing demand, increasing revenue and decreasing costs through the addition of productive use of energy will result in more viable micro-grid business models. Because productive uses account for the majority of demand for electricity, increasing productive use should contribute to the economic viability of microgrids[13].

TABLE IV. CHARACTERISTICS OF SELECTED PRODUCTIVE USE APPLIANCES IN 2019

Sector	activities/ appliances	Power required (kW)	Cost from supplier ($)	Payback period (months)
Primary industries: agriculture, fishing	Egg incubator	0,08 to 0,16	50 to 100	1 to 3
	Grinder for pulses and beans	5.2	1,500 to 4,000	6 to 12
	Water irrigation pump	3.7 to 22.4	200 to 1000	3 to 6
	Sterilizer (for dairy processing)	3 to 6	600 to 2,000	1 to 3
	packager	0,25 to 3	500 tp 1,000	6 to 12
Light manufacturing	Electronic welding machines	3 to 7.5	200 to 300	6 to 12
	Jigsaw	0,4	100	3 to 6
	Electric drilling machines	0,4	20 to 50	3 to 6
	Popcorn maker	1.5 to 2.1	50	1 to 3
Commercial and retail activities	Computer	0,015 to 0,1	250 to 800	3 to 6
	printer/scanner for stiationary	0,5 to 2	150 to 250	3 to 6
	Sewing machine	0,2	30 to 100	3 to 6
	Television for local cinemas and bars (including decoder)	0,05 to 0,2	100 to 200	1 to 3

Source: ESMAP 2019

Skills and local business development are also another critical component of any project promoting PUE. Firstly, the local entrepreneurs have to be trained to operate the renewable energy technologies and maintain them. They also need to be trained in the use of the appliances. Secondly, business and management training are important particularly for early entrepreneurs. The developers, NGOs and local associations can play an important role in this regard.

Cooperation and the sharing of best practices is an important part of capacity building. This exchange need to occur on multiple levels including on the political and international level as well as on the industry level. There is already positive development on the international front. Intercontinental cooperation can be seen through programs such as Africa-EU Energy Partnership (AEEP) and the Africa-EU Renewable Energy Commission which are supported by the European Commission and the African Union Commission. On the industry level, well established associations such as Alliance for Rural Electrification (ARE) can and are playing a important role in sharing knowledge, experience and best practices[14].

A number of successful productive use energy projects have been implemented in Africa that confirm the importance of a holistic approach that combines financing schemes, market approaches, capacity building and participation of the local community. For example, Energising Development (EnDev), a multi-donor programme managed by GIZ and the Dutch agency Netherlands Enterprise Agency (RVO), initiated a programme whose key objective is to provide modern energy services for productive uses in agriculture and small-scale manufacturing in 7 regions in Ghana. The programme comprises four components: grid electricity for irrigation, solar pumps for irrigation, improved cookstoves and a monitoring of electrified light industrial zones. The programme pursued access to energy through subsidies to connect to the grid or finance the purchase of decentralized energy systems such as a solar irrigation system. In addition, the programme pursued a market-based incentive scheme that supports 300 small scale agri- processors to access institutional cook stoves. Furthermore, EnDev work with local business associations and authorities to provide business development services as well as technical support and training to farmers utilising electricity from the grid and to providers and users of the solar irrigation systems. The first phase of the programme has been a success and has witnessed 1000 MSMEs founded/relocated and 3000 employment opportunities created. The Programme has resulted in 417 MSMEs with 700 employees and total of 1,600 people with new access to electricity. Furthermore, in the majority of the areas in which the program was implemented, there are dialogue platforms for local governments and business associations were established [15].

IV. Conclusions

Off-grid renewable energy solutions are best placed to drive rural economic transformation due to their ability to reach millions of people that are not connected to the central grid. Moreover, there is a compelling case for Africa to prioritise renewable energy options given the continents vulnerability to climate change and its limited ability to adapt to negative effects of climate change particularly on agriculture. However, in order to realise the potential for productive use leveraging renewable energy, there is need to overcome barriers to widespread adoption renewable energy for productive use in rural areas.

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Campus universitaires : acteurs majeurs de la transformation de la société dans une perspective de transition énergétique et de développement durable.

Duvaut Thierry
Institut de Thermique, Mécanique, Matériaux
Université de Reims Champagne Ardennes
France
thierry.duvaut@univ-reims.fr

Abstract— L'objectif de cet article est de mettre en évidence le rôle central que peuvent (et doivent ?) jouer les établissements supérieurs dans une stratégie internationale, nationale et territoriale de lutte contre le changement climatique.

La politique climatique se décline actuellement en objectifs internationaux, engagements nationaux ou autres plans territoriaux, mais on peut se demander si les établissements supérieurs d'enseignement et de recherche et leurs campus universitaires ne pourraient pas apparaître comme la première chaîne de l'édifice en tant que sites démonstrateurs de la transition énergétique. Nous allons prendre comme exemples le projet d'éco-campus Rémois, l'Ecole Polytechnique de Catalogne ainsi que le projet de Sèmè City pour montrer l'importance pour ces structures de décliner une stratégie de développement durable et de transition énergétique. Nous prendrons également appui sur certains développements scientifiques Africains en matière de constructions durables.

Keywords—Eco-campus; Construction Durable; Efficacité énergétique; Développement Durable

I. INTRODUCTION

L'objectif est de montrer comment une recherche et un enseignement pluridisciplinaire (dans les domaines de l'énergétique, des sciences de l'ingénieur, de l'environnemental, des sciences de l'homme, et de la socio-économie) et multi-échelles (du bâtiment, de l'ilot, pour aller vers le quartier, la ville et l'agglomération) peuvent apporter des réponses sur la capacité d'un système urbain, par exemple un campus universitaire, à s'engager dans la voie du développement durable, et quels sont les impacts urbanistiques notamment en matière de constructions et d'usages ?

Il s'agit donc d'analyser nos connaissances sur l'efficacité énergétique, les impacts environnementaux, la qualité de vie professionnelle (ici des étudiants et des personnels), et l'interaction avec le monde environnant. Ces enjeux d'habitat, de mobilité, du bien vivre ensemble, et des interactions entre les différents acteurs du campus et du quartier viennent aussi interpeller des problématiques relevant de la performance des bâtiments, des modes et des plans de circulation, de l'organisation intrinsèque du quartier et de la ville, de l'accès fluide et efficace aux ressources et aux services (économie circulaire), et de l'adaptation des réseaux et des infrastructures (notamment électrique) à de nouveaux besoins émergents (gestion urbaine plus intelligente et numérique). Nous tenterons d'effectuer une analyse africaine de ces questions en prenant principalement l'exemple du Bénin.

II. ECO-CAMPUS UNIVERSITAIRES

Le premier campus créé comme un projet de ville universitaire durable est certainement le projet d'université de Louvain La Neuve en Belgique débuté dans les années 60 [1] et qui accueille aujourd'hui 20 000 étudiants dans une ville de 30 000 habitants construite autour et avec ce projet d'éco-campus universitaire. Une phrase résume assez bien cette ville : « *Louvain-la-Neuve a été créée par l'université et pour l'université.* ».

Cité en exemple comme le premier campus ouvert sur la ville (à l'inverse des campus américains refermés sur eux-mêmes) ayant mis en avant la notion de développement durable au cœur du projet, il a été source d'inspiration pour un certain nombre de projets d'éco-campus et en particulier sur celui de l'Université de Reims Champagne Ardenne dont nous allons vous parler ici (même si ce projet n'a pas abouti pour des raisons politiques).

A. Les Enjeux

Tout part du constat que les établissements d'enseignement supérieur doivent être considérés comme des leviers majeurs de la transformation de la société dans une perspective de transition énergétique et de développement durable, et ce à plusieurs titres :

- ils représentent une surface non négligeable du bâti public (à peu près 1/3 en France)
- le public étudiant est nombreux et l'enseignement doit promouvoir ces valeurs de développement durable
- par leurs activités de recherche, ce sont des lieux d'élaboration du savoir et d'innovations du futur, notamment sur de nouveaux modèles de société à construire face aux enjeux climatiques.

C'est dans ce cadre qu'un projet d'éco-campus doit pouvoir s'élaborer, et le projet d'éco-campus de Reims reposait sur les éléments suivants :

- Refondation de l'université sur un seul site rémois au lieu de 7 initialement.
- laboration du futur éco-campus comme un site démonstrateur en matière de développement durable.
- Intégration du développement durable et de la responsabilité sociétale dans la stratégie d'enseignement, de recherche et d'innovation de l'établissement.
- Elaboration et animation d'une démarche générale de développement durable en lui conférant une pleine dimension stratégique, partenariale et participative à l'échelle de l'université, mais aussi du quartier et de la ville.
- Elaboration d'un Plan d'action énergétique.

B. Le projet d'éco-campus Rémois

L'Université de Reims Champagne Ardenne est une universitaire pluridisciplinaire de 25000 étudiants et environ 3000 personnels administratifs et techniques et enseignants-chercheurs, avec une trentaine de laboratoires de recherche.

Il s'agit donc d'élaborer non seulement un éco-campus mais aussi un véritable quartier de vie universitaire, et dans un quartier populaire de la ville [2]. Le premier point important est l'intégration du campus dans son territoire, et à l'inverse de la plupart des campus américains, être ouvert sur le quartier en liaison étroite avec le projet urbain de la ville, notamment :

- par la gestion des interfaces avec l'environnement immédiat
- par la mise en place d'une politique cohérente de déplacements en lien avec la ville (transports, déplacement et flux de personnes), en privilégiant les « déplacements doux » (tramway, vélos, parcours piétons,…), et un campus interdit à la voiture (sauf en périphérie).
- par une mixité des usages (bâtiments en gestion commune avec la ville comme des infrastructures sportives, ou des musées issus de la recherche universitaire et de ses collections par exemple), et le positionnement de services à l'intérieur du campus (restauration, banques, services publics, librairies, magasins de proximité, …).

L'aménagement du site devait effectuer selon une approche environnementale de l'urbanisme. Il s'agit d'apporter un confort de travail pour les étudiants et les personnels de l'université en s'appuyant sur des critères environnementaux précis :

- Mobilité douce et intermodalité à l'intérieur du campus (parcours piétons, parcours de biodiversité gérés par les départements d'enseignement et les laboratoires de recherche concernés, vélo mis à disposition gratuitement, parking dédié aux vélos avec possibilité de réparation du matériel, …).
- Constructions favorisant le fonctionnement par ilot de 2 à 3 petits bâtiments (3 étages maximum) pour optimiser une architecture raisonnée et compatible avec une gestion des déchets, de l'eau, de la biodiversité, de l'énergie à l'échelle de l'ilot, élaboration d'espaces boisé, de convivialité en pleine nature, d'espaces de loisir (beach volley, plage, pétanque, …).
- Plan de gestion et de récupération de l'eau à l'échelle du campus mais aussi de chaque ilot de bâtiments, élaboration de plans d'eau favorisant la biodiversité.
- Plan lumière et de gestion des éclairages privilégiant notamment l'éclairement solaire, l'utilisation d'éclairage minimaliste en énergie et programmé, restreignant au maximum les espaces sombres par soucis de sécurité des personnes.
- Un plan de gestion de déchets (usages et traitement), implantation de fontaines à eau pour bannir l'utilisation des bouteilles plastiques, récupération et tri des déchets, …
- Elaboration d'une économie la plus circulaire possible en matière de restauration universitaire (plantation de vergers, jardins potagers partagés, circuits courts de distribution avec les agriculteurs environnants, traitement des déchets pour produire des engrais verts, station de lombriculture, …).

Il s'agissait bien entendu d'avoir une approche la plus optimale possible en matière de rénovation énergétique des bâtiments restants sur le site, de constructions durables et écoresponsables pour les nouveaux programmes immobiliers, et de gestion de l'énergie sur le site.

Ainsi les bâtiments devaient être construits suivant les normes de haute performance énergétique (basse consommation voire produisant plus d'énergie que consommée) en privilégiant des matériaux de construction innovants et écoresponsables (béton de chanvre par exemple), des solutions mix énergétique du site avec identification des gisements d'énergie renouvelable.

Un élément important résidait dans la multifonctionnalité et l'adaptabilité des bâtiments (passage de fluides et de gaines spécifiques lors de la construction permettant une utilisation aussi bien en enseignement qu'en recherche, parois modulaires pour s'adapter à des capacités différentes, …) permettant ainsi non seulement une durabilité d'utilisation, mais aussi un taux d'occupation optimisé.

Enfin, il est important de souligner que pour l'ensemble des points traités, nos unités de recherche pluridisciplinaires pouvaient participer à l'élaboration stratégique du campus, comme par exemple :

- Laboratoire de biodiversité pour la partie écomusée et l'élaboration des parcours piétons de biodiversité, ainsi que la gestion de cette biodiversité dans le campus.
- Laboratoires d'urbanisme et de sociologie sur la partie urbaine, gestion des déplacements, intégration dans la ville, association et appropriation des utilisateurs du campus.
- Laboratoires de sciences économiques et de gestion sur la partie économie circulaire et gestion du campus.
- Les laboratoires de Sciences de l'Ingénieur et des Matériaux sur l'instrumentation et le suivi des bâtiments, ou sur l'implantation, le suivi et la gestion énergétique du campus.

C. *Conclusion*

Plutôt que définir ce qu'est un éco-campus, il nous semble plutôt important de s'attacher à la mission de conception d'un éco-campus. Comme nous avons essayé de le montrer, il devrait obéir à deux problématiques principales :

- Contribuer fortement à la qualité de vie des usagers (personnels et étudiants), et au rayonnement de l'université aussi bien par ses activités pédagogiques, de recherche, ou de vie sur le campus. Bien entendu, en associant tous les futurs utilisateurs dans une démarche de participation à la conception, tout en s'inscrivant dans le projet de territoire et de la ville. C'est un marqueur sociétal fort.
- Développer une approche globale et pérenne en prenant en compte l'ensemble des problématiques de développement durable et d'écoconstruction, aussi bien sur les aspects énergétiques, de biodiversité, que de responsabilité sociétale.

III. Importance des usages dans les campus : exemple de l'universite polytechnique de Catalogne

Avant d'aborder des exemples issus de ma maigre expérience africaine, je souhaitais montrer l'importance des pratiques et des usages dans les campus de pays chauds dans le domaine des économies d'énergie et de fluides en m'appuyant sur une conférence sur « Usages, stratégie & économies d'énergie » donnée par Mr Didac Ferrer qui était le responsable de Gestion Durable et d'Egalité des Chances à l'Universitat Politècnica de Catalunya [3].

C'est un campus universitaire de 40 000 étudiants, 4 000 personnels, et 90 bâtiments (400 000 m2 construits). A partir du constat que la consommation et la dépense énergétiques étaient en constantes augmentations entre 2003 et 2010 (passage de 37 à 55 MWh pour une facture énergétique de 2,9 à plus de 5M€), un plan d'efficacité énergétique a été mis en place avec comme objectif de réduire de 25% la consommation totale entre 2010 et 2014. Cette consommation importante d'énergie est principalement due à l'utilisation excessive de la climatisation.

- Le monitorage des bâtiments afin d'établir un constat réaliste de la consommation énergétique bâtiment par bâtiment (plus de 200 points de mesures sur les 90 bâtiments, et le personnel technique formé à ces mesures, avec un budget de 200 k€).
- Travaux de maintenance sur les appareils défaillants et réhabilitation de l'isolation thermique des bâtiments « passoires thermiques ».
- La responsabilisation des usagers par la formation à l'efficacité énergétique des usagers, et par la nomination d'un responsable efficacité énergétique sur 1 ou plusieurs bâtiments sur la base du volontariat (13 en 2011, 42 en 2014, 200 en 2018), par des concours du bâtiment le plus économe (sur chaque bâtiment visualisation en temps réel de la consommation énergétique), et par des consignes de températures internes définies à 20°C maximum en hiver et 26°C minimum en été mais pouvant être modulées par les usagers en dessous en hiver et au-dessus en été.
- a rationalisation de l'utilisation des bâtiments et la modification des habitudes et des routines pour créer une culture de l'utilisation rationnelle des ressources. Les horaires d'ouverture des bâtiments ont été modifiés en fonction de la période (ouverture plus tôt le matin et plus tard le soir mais fermeture aux heures chaudes de la journée en été, et bien entendu le contraire en hiver par exemple), période de fermeture du campus réellement appliquée (le week-end et les périodes de vacances pour éviter de chauffer ou de climatiser les bâtiments pour un très petit nombre de personnes). Ces directives n'ont pu être mises en place qu'après une période assez importante de concertation pour y faire adhérer l'ensemble des personnels et étudiants. En été 2013, ces mesures ont été couplées avec un « droit à la climatisation » de 5 heures/ jour uniquement. Cette acceptation des usagers a été favorisée par une transparence et une accessibilité à l'information en temps réel tout au long de la mise en œuvre du Plan d'Efficacité Energétique (notamment avec un système d'informations par courriel et un site internet dédié).
- La mise en place d'appareils moins énergivores quand cela été possible (ampoules basse consommation, appareil de recherche, …), d'appareils de bien être non énergivores (fontaines, ventilation double peau extérieure aux bâtiments, panneaux d'information,…).
- L'appel aux activités de recherche des laboratoires pour que le campus devienne l'objet de ces activités, et des audits énergétiques effectués par des étudiants, ainsi que différentes thèses menées sur la consommation énergétique des bâtiments, ou sur la notion de « bâtiments vivants ».

Les résultats sont très significatifs puisqu'il a été observé une baisse de la consommation mensuelle d'électricité de 21%, de celle de gaz de 41%, de la consommation énergétique en kWh de 27%, pour une baisse de la dépense énergétique chiffrée à plus de 4M€ par rapport à un scénario sans intervention.

Un autre aspect de ce plan d'efficacité énergétique est la forte implication de la communauté universitaire en particulier en ce qui concerne la gestion de l'énergie et les usages, et le fait que cette communauté est fière des résultats obtenus. Un aspect bénéfique réside aussi dans le fait que les bénéfices réalisés sont réinvestis pour la poursuite du plan d'efficacité énergétique, générant ainsi d'autres bénéfices avec un effet extrêmement vertueux.

Ce plan d'efficacité énergétique est très certainement transposable dans les pays africains pour lesquels les problématiques sont sensiblement identiques.

IV. Exemples de projet de recherche africain pour un habitat durable

Indépendamment de construire un campus durable, j'ai été frappé par le fait que la plupart des bâtiments au Bénin par exemple (que je connais un peu mieux), sont construits sur des modèles ne prenant que très peu en compte la transition énergétique et le développement durable :

- Dans les matériaux utilisés (principalement du béton, …)
- Dans la façon de construire avec très peu de considération de l'énergie grise.

- Avec très peu de critères d'isolation thermique
- Avec une emprise de la climatisation au détriment de l'efficacité énergétique
- Avec très peu d'utilisation des énergies durables

Pourtant des laboratoires de recherche de l'Afrique de l'ouest ont des activités reconnus dans ce domaine et en particulier dans l'utilisation de produits de constructions autochtones présentant des propriétés mécaniques, hygrométriques, et d'isolations thermiques et phoniques tout à fait satisfaisantes et compétitives. J'en donne deux exemples parmi d'autres ci-dessous

A. Habitat durable: carreaux revêtus de granitos (Bénin)

Le premier exemple est issu des activités de recherche menées au sien du laboratoire d'énergétique et de mécanique appliquée de l'Ecole Polytechnique d'Abomey Calavi par le Professeur Chakirou Toukourou. Il s'agit de la thèse de Mr Bachir Ambelehoun sur la caractérisation hygro-thermomécanique et étude de durabilité d'un matériau bicouche minéral: cas des carreaux revêtus de granitos [4].

Cette thèse a montré les bonnes performances et la durabilité des carreaux revêtus de granitos tout en caractérisant de manière physicochimique ses constituants issus du Bénin (granite de Zangnanado, marbre de Bagbononhoué, sable d'Afanmè).

Ces études ont montré non seulement les propriétés d'isolations thermique et acoustique du matériau, mais aussi une bonne résistance mécanique.

Plusieurs bâtiments ont pu être construits et ont permis de valider l'utilisation de ce type de matériau, et confirmer les propriétés attendues d'un point de vue thermique, mécanique, et phonique.

B. Habitat durable: matériaux biosourcés à base de Typha (Sénégal)

Le second exemple est issu des activités de recherche menées conjointement à l'Université de Thies (sous la direction de Salif Gaye) au Sénégal et à l'Université de Reims Champagne Ardenne en France (sous la direction de Ton Hoang Mai). Il s'agit de la thèse de Mr Ibrahim Niang sur la « Contribution à la certification des bâtiments durables au Sénégal: cas d'étude des matériaux de construction biosourcés à base de typha. » [5].

Elle a permis d'élaborer un agro-matériau à base de terre argileuse et de granulats de Typha (roseau invasif) pour des projets de constructions durables. Les performances mécaniques et d'isolation thermique de ce matériau sont tout à fait remarquables, puisqu'elles sont égales voire supérieures aux propriétés du béton de chanvre. Avec des performances hygrométriques accrues, une bonne tenue mécanique, une isolation thermique très satisfaisante, et des propriétés d'ininflammabilité, le béton de Typha est un candidat parfait pour être utilisé comme matériau de construction.

Deux maisons d'habitations ont été construites après cette thèse.

C. Conclusions

Ces deux exemples parmi d'autres viennent montrer que les activités de recherche menées peuvent déboucher sur la valorisation de produits autochtones (ici des carreaux revêtus de granitos d'une part et le béton de Typha d'autre part) dans le domaine du Génie Civil. Il est à noter que le Typha est très invasif (800 000 hectares envahis) et qu'il est considéré comme nuisible alors qu'il pourrait être utilisé efficacement comme matériau de construction durable.

Il reste maintenant à faire la promotion de ces géomatériaux locaux de construction durable, et surtout avoir la volonté économique et politique de créer et élaborer une chaîne industrielle complète.

V. PROJET INNOVANT AFRICAIN : SÉMÉ CITY

Je terminerai par un exemple exceptionnel et unique concernant le développement de ce que j'appellerai un campus africain dédié au savoir et à l'innovation et qui pourrait se rapprocher de l'idée d'un éco-campus africain.

Il s'agit du projet Béninois de Sèmè City promu par le gouvernement Béninois et dont la conception et la gestion ont été confiées à l'Agence de Développement de Sèmè City. Elle a pour mission de concevoir, planifier et développer une ville intelligente et durable offrant un cadre stimulant et favorable pour promouvoir le savoir, l'innovation et l'entrepreneuriat au service du développement durable et inclusif.

Aussi appelée « La cité Internationale de l'innovation et du Savoir », Sèmè City va se construire par phases successives à partie de 2019 jusqu'à l'horizon 2030. Avec pour projet en 2021 (certains bâtiments ont déjà été construits), de développer la future écocité africaine intelligente et durable qui s'étendra sur 200 hectares. Cette écocité sera un laboratoire à ciel ouvert pour les chercheurs, entrepreneurs et étudiants.

Comme le dit Claude Borna, Directrice Générale de l'Agence de Développement de Sémé City, *« Sèmè City, c'est avant tout un lieu unique où se rencontrent des talents à qui nous donnons l'opportunité d'apprendre ensemble, de s'entraider et de dépasser leurs limites. »*

VI. CONCLUSIONS

L'objectif était de montrer comment une recherche et un enseignement pluridisciplinaire (dans les domaines de l'énergétique, des sciences de l'ingénieur, de l'environnemental, des sciences de l'homme, et de la socio-économie) et multi-échelles (du bâtiment, de l'ilot, pour aller vers le quartier, la ville et l'agglomération) peuvent apporter des réponses sur la capacité d'un système urbain, par exemple un campus universitaire, à s'engager dans la voie du développement durable, et quels sont les impacts urbanistiques notamment en matière de constructions et d'usages ?

Nous avons essayé d'apporter des réponses par des exemples de projet d'éco-campus (projet Rémois) ou d'un campus existant comme l'Université Polytechnique de

Catalogne dans lesquels les acteurs du campus (personnels et étudiants) peuvent être les promoteurs d'une stratégie en matière de développement durable et de transition énergétique.

Nous avons montré, par des exemples d'activités de recherches en Afrique de l'Ouest, que la faisabilité d'une filière de construction durable à partir de matériaux locaux était envisageable, et pouvait être une alternative efficace et durable à une construction plus dispendieuse énergétiquement et moins soucieuse de l'environnement.

Enfin, le projet d'un écosystème proche d'un éco-campus, Sèmè City démontre tout le potentiel que peut développer le continent Africain sur ce sujet des éco-campus, de la transition énergétique, du développement durable, et de leur impact sur la société civile.

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Energy Demand Drives Innovation

Monica Gullberg
Division of Mitigation and Adaptation
Green Climate Fund, GCF
Incheon, South Korea
mgullberg@gcfund.org
Disclaimer: this article is the authors own work and not statements from the Green Climate Fund

Abstract: The future sustainable energy systems in Africa need to stem from a sensible demand analysis, including efficient and well targeted energy services for health, food, housing and diversification of the economies. This paper aims to inspire planners in different end user sectors to understand the significance of energy planning and take the lead in articulating priorities. Focus on supply is secondary. Efficiency, storage and flexibility can be mastered through long term integrated planning of demand, inclusiveness and innovative processes. Capturing demand through being open minded to un-conventional solutions, with supply targeting specified demand in optimized, smart energy service rather than copying established supply models and demand projections based on these may support that Africa leads economic growth in the centuries to come. In addition to the urban growth and induced transport needs, important growing demand sectors include housing, SME's, basic health care, agriculture, and new industries following on diversification of economy and trade. Measures that the demand sectors can use include integrated long-term planning, pipeline development, regulation, procurement, catalytic procurement, innovative design, architecture competitions. Business models that will enable these investments can be leasing, shared risk agreements, guaranteed service/saving agreements and variants of Build Own Operate and Transfer agreements For financial schemes, a challenge is to ring-fence investments, define services and create scale in a way that the operating expenses and savings are integrated in the structure.

Keywords—energy demand, needs-based, energy efficiency, integrated planning, financing energy transition

I. INTRODUCTION

On a global scale, energy system design, providing stronger incentives for reduced GHG-emissions in supply and increased end-use efficiency, will be critical for reducing the risk of irreversible, catastrophic climate change.

Energy efficiency, a higher degree of renewable energy in primary supply, and an increased electrification of different energy end-use sectors will be required, along with universal access to renewable energy. Traditionally strategic energy planning has been centered on optimizing the supply of energy based on an anticipated load and load growth. There are however reasons to have demand sectors step up to take a more proactive role in the strategic energy transition. This paper will outline some arguments for why an increasingly demand driven and needs-based planning will be paramount.

Energy demand in Africa will develop as a consequence of population growth, the economic development and diversification as well as the urbanization [1].

New technologies based on renewable energy can provide new decentralized solutions to some of the up-coming energy needs, especially if these are assessed from a feature-based approach and with processes being adjusted to cope for variation in supply. For off-grid as well as for on-grid, the load flexibility and predictability will be of key importance to achieve resource efficient supply. In the end, consumers will be paying for the transition, why it will be important that consumers have resources to pay. This in turn is supported if customers get tailored services and value for money.

A well-performing energy system that improves efficient access to modern forms of energy would strengthen the opportunities for the world's poorest few billion people to escape the worst impacts of poverty.

For example in sub-Saharan Africa "energy-poor" suffer the health consequences of inefficient combustion of solid fuels in inadequately ventilated buildings, as well as the economic consequences of insufficient power for productive income-generating activities and for other basic services such as health and education. In particular, women and girls in the developing world are disproportionately negatively affected in this regard.

For sub-Saharan Africa, developing sustainable energy systems may require:

- Rational plans to accelerate the deployment and provision of modern energy services
- Re-orienting regulatory policy frameworks, including tariff structures and market regimes, to stimulate business innovation and private sector participation
- Improvement in the design and careful targeting of energy subsidies
- Further investment in the capabilities of public utilities
- A phased introduction of renewable and low-GHG emitting technologies, and
- The introduction of energy efficiency measures wherever feasible.

For example, in the SADC (South African Development Community) renewable energy and energy efficiency strategy and action plan (2015 to 2020) REESAP 1[ref ?], which is a broadly anchored policy paper, it is mentioned that energy efficiency planning is recommended at the national level. It is put forward that potential objectives could for example be to reach at 15% energy savings by 2030 relative to an established base line. Also, at the regional level, it is mentioned that an Energy Efficiency financing plan is expected. As part of the action plan, the need of data for proper planning is mentioned[2].

II. Outlook for Energy Demand in Africa

Traditionally, biomass and waste have been extensively used and are still by far the most common source of energy in Africa.Road transports is the second main energy use. In 2018, 124 Mtoe of fuel was used for road transports, almost exclusively oil in the form of products [3]. Energy use in the African transport sector was only 20 Mtoe in the seventies, so it has been a 6-fold increase in 45 years.

Total African electricity use has increased from less than 100 TWh in 1973 to 682 TWh in 2018. The International Energy Agency (IEA) estimates that the total consumption will amount to around 1800 TWh by 2040 [4]. Scenarios made by the IEA estimate that the non-industrial electricity uses will increase more than the industrial. Also, it is foreseen that sub-Saharan Africa will have the most rapid increase.

In Africa, electricity is mainly used in industries and other sectors, whereas electricity uses in the transport sector are negligible. These sectors are referred to throughout the world in energy statistics. The sector Other cover residential, commercial and public services, agriculture/forestry, fishing and non-specified other.

To large extent, electricity uses in these sectors can be referred to buildings' electricity use but also to out-door infrastructure such as e.g. water and sewage systems, irrigation systems, public lighting, road lighting and lighting and control systems in ports and airports.

More specific statistics on different electricity end-use within in the African non-industrial sector is scarce. Based on some national case studies and observations, it can be assumed that the main electricity end-uses are appliances (including cooling and ventilation) and lighting as well as space and water heating, especially in cooler climates.

Mapping current demand and supply deficit through inventories and needs assessments would be the first priority step to take in reaching a sustainable energy system in African countries. The various energy end use sectors need to contribute to the inventory, and understanding of needs.

Quantifiable and comparable statistics will be required to understand trends. Also, qualitative studies will be crucial in order to understand priorities and values of different energy services. Projecting and anticipating future needs is the next challenge. For this, having a constructive dialogue and innovative process is paramount.

III. Factors Influencing Power Demand in Africa

More than half a billion people will be added to Africa's urban population by 2040. This is high if compared to China during their economic growth. How Africa meets its growing energy needs is crucial for the continent's economic and energy future, as well as for global trends.

Growing urban populations mean rapid growth in energy demand for industrial production, cooling and mobility [4].

A. Population growth

By 2030 the African population is foreseen to exceed that of Europe, South and North America combined.

The population of sub-Saharan Africa is projected to grow fast, and is on course to double by 2050 [5]. A growth rate that will make Africa more important than ever to the global economy.

Africa currently has a low population density. Forecasts for Africa indicate that average densities will increase from 34 to 79 persons per square kilometer between 2010 and 2050 [6].

The boom in Africa's population will be in sub-Sahara, including growth in countries like Tanzania, which is one of the poorest countries on earth.

Nigeria is set for one of the biggest population booms in world history and it's expected to increase by a factor of eight in just two or three generations.

B. Urbanization

Fast growing cities in a changing economy bring along new social challenges. More than a quarter of the 100 fastest-growing cities in the world are in Africa. At the same time, high resource depletion levels in African economies forecasts a changing economy [7].

Because of their rapidly increasing populations, spatial sizes and huge economic significance, African cities are key channels for leading the world in the transition to sustainable economic growth trajectories. It is quite possible therefore, that progressive and innovative global initiatives may boom in Africa [7].

African countries and cities are burdened by high infrastructure deficits and shortages in access to technologies and services.

In order to have an economic diversification, careful and urgent reconsideration of all infrastructure and technology options available, including energy technologies are required, because present and future policy decisions shall lock African countries into investment patterns that will determine production and consumption levels for decades to come.

Africa's urban transition is proceeding rapidly with the accumulated relative growth rate of its cities now among the highest in the world. More specifically, between 2010 and 2050, the number of Africa's urban dwellers is projected to increase from 400 million to 1.26 billion.

The form and management of urban areas can have a profound impact on both the effectiveness of the transport system in reducing its GHG impact, especially in relation to reducing forced mobility and more effective inter-modal operation, and on the resilience of the population [8].

C. Economic development and diversification

Africa's economy has been severely affected by the COVID pandemic. Africa, have not yet had the means or opportunity to start mass vaccination campaigns of scale and remains very vulnerable to the spread of more transmissible variants of Covid-19. Only less than 10% of population is vaccinated [5].

Corona has made people lose jobs and income. Education has been disrupted and in many senses, a young generation's opportunities are deprived. Peoples household economy is not assumed to recover until 2025 [5].

In the longer term, however, Africa has the world's highest projected GDP growth (4.2 % compared to world average 3%) [5].

It is anticipated that African economies will diversify. Commodity exporters may focus on vertical diversification that takes advantage of their existing comparative advantage. Others may instead diversify horizontally into new areas; such as Ethiopia's recent move into textiles [5].

Diversification generally requires broad-based horizontal policies, such as tackling government failures, ensuring macroeconomic stability, and avoiding exchange rate overvaluation.

In addition, however, countries have also often looked to various forms of industrial policy to actively promote diversification into targeted sectors.

Horizontal diversification in a country can be underpinned by the general business investment climate including low levels of corruption, functioning infrastructure such as reliable electricity, roads and internet, well-functioning governmental institutions and other features that contribute to competitive advantage for international industries [9].

Without knowing what different African countries may want to prioritize, it is likely that food production will modernize.

In parts of Africa for which power supply is yet not available, the economic activities center on agricultural activities, self-subsistence farming, silvo-pastoral activities, forestry and often with limited access to markets for offset of processed products. The prospects of commercial food production in Africa is paramount and the food industry should be ready to invest in sustainable value chains.

Modernization of the agricultural sector will render increased energy uses in all three end use sectors as illustrated in Table 1.

TABLE 1 EXAMPLES OF ELECTRICITY END-USES EVOLVING IN EACH OF THE THREE MAIN GLOBAL STATISTICS SECTORS (INDUSTRIAL, TRANSPORT AND OTHER) FOLLOWING A MODERNIZATION OF THE AGRICULTURAL VALUE CHAIN

Agri-cultural value chain	**Farming**	**Processing**	**Transportation**	**Vending**
Energy end use sector (OECD)	***Other***	***Industrial***	***Transport***	***Other***
Type of energy end use	Irrigation	Lighting	Vehicles	Lighting
	Cattle keeping	Drying	Cool storages	Dry storages
	Heating	Graining		Cool storages
	Lighting	Milling		
	Dry storages	Pressing		
	Cool storages	Cooling		
	Industrial Fertilizer production	Cutting		
		Vacuum packaging		

D. Conclusions

African electricity demand growth is paramount and rapid.

Green field investments are required.

Beyond the energy sector, many other sectors need to contribute actively to achieving a sustainable energy system because demand will grow in different sectors; industries both process and manufacturing industry, food industry, construction industry, the transport sector and public service sectors such as the health and education sectors.

IV. CURRENT AND FUTURE FEATURES OF ENERGY TRANSITION IN AFRICA

There are challenges with reaching at sustainable energy systems all over the world. In Africa the challenges include that 570 million people in Sub-Saharan Africa still do not have access to electric energy and 906 million have no modern cooking but rely on three-stone fire-places for their cooking needs [5].

The impact of the pandemic on household incomes has weakened the ability to pay for electricity. Progress towards universal energy access has stalled, especially in sub-Saharan Africa. For the first time since 2013 In 2019, in sub- Saharan Africa, almost half of people without access could not afford electricity for an essential bundle of services, even if provided with a connection. In 2020, around 50 million people in developing countries in Asia and Africa reverted to the traditional use of solid biomass for cooking [5].

Emerging electricity uses are however expected in both the industrial and non-industrial sectors over time. Also in the transport sector, electricity demands are likely to increase over time, although the strong reliance the second-hand vehicle market contributes to EVs becoming available with a time lag [5].

Augmented investments in the supply side through for example independent power producers with the national grid as off-takers, or through private investors in mini-grids and off-grid services will continue to be of central concern in African countries.

In African Power systems, the proportion of renewable energy in the electricity mix generally have to increase. Countries that for decades have relied on hydro power have experienced more frequent and longer power outages as a consequence of increased droughts. In many cases, thermal power plants (fuel oil, gas or coal) have been established to complement the deficit. Renewable energy is increasingly competitive. Still, some years back, the renewable options required stronger finances than countries could avail at the time, while the fossil options came at good deals.

African countries over all represent very low per capita electricity consumption if compared to developed countries. In absolute terms, however, African countries' average energy intensity level is higher than in the developed countries, because of technical and non-technical losses in all parts of the system.

In Africa, there are substantial energy efficiency improvement opportunities on both the supply side and the demand side. On the supply side, the power sector has substantial potential to improve the efficiency of power generation and to reduce transmission and distribution losses, thereby reducing the amount of primary energy (e.g., coal, gas, oil) consumed for the same output.

Demand side opportunities include end-use efficiency opportunities in industry, non-industrial sectors (for example: buildings, agriculture and public services) and transport.

Energy efficiency has just in recent years been put on the agenda in Africa, even though there were some demand side management initiatives in the eighties, before structural adjustments and energy sector deregulation. Today, energy efficiency is struggling with new business models, financing schemes and regulations. Not many African countries have an Energy Efficiency Agency or similar institution[18]. Minimum Energy Performance Standards (MEPS) and other performance requirements are scarce, and commercial energy service offers too. More than this, in NDCs (Nationally Determined Contributions), energy efficiency is often mentioned in rather general terms, while the more specific, strategic and step wise implementation planning is often lacking.

In many sectors, the nature of the energy transition opportunity is similar for both developed and developing countries. In sectors with long-life assets, however, it differs. In African countries, much of the energy efficiency potential in buildings, industry and power is associated with greenfield opportunities (i.e., new buildings, new industrial stock). There is a need to move quickly on these infrastructure opportunities: continuing to expand the use of energy-inefficient solutions can lock in infrastructure that will require high energy consumption and carbon emissions for 40 years or more. While retrofit opportunities do exist, they tend to be more expensive.

Investing in power grid infrastructure, including storage and flexibility, enables the effective harnessing of renewable energy resources.

While regional transmission lines are planned since long, the financing of the same has failed to materialize and the current IPP(Independent Power Producer)-based power market structure does not include grid optimization in the PPA's(Pawer Puchase Agreements). Rather, these investments still require public finance to a large extent.

Power-pooling and regional power trade have not matured in Africa apart from a limited trade in the MENA (Middle East and North Africa) region and even less in the SADC power pool SAPP. In general, there is no actual power trading going on.

With the current generation mix in many countries, interregional transmission may well also contribute to prolonging the lifetime of existing fossil power plants whose marginal cost may still be lower than new renewable energy.

V. Financial Challenges

Financing is a significant obstacle, since many of the investments – especially those serving rural areas and very poor communities – require public financial support via concessional and blended finance structures (IEA, 2021a) [ref?] together with improvements in tendering and administrative processes, while at the same time low demand can make it hard to attract private capital.

Achieving full electricity access by 2030 requires annual investment of over USD 35 billion. This is a tiny fraction of global total energy investment, but well above what is being spent today: investment in electricity access in sub-Saharan Africa is only around 15% of what will be required.

Current investment in clean cooking in sub-Saharan Africa represents only about 3% of the capital expenditure required to reach full access (SE4ALL and CPI, 2020). [5]

VI. The Role of Demand Driven Energy-Ambitions for Overcoming Challenges

In many respects, supply-side targets are easier to capture in the short to medium term, because there are fewer institutional barriers than on the demand side. On the other hand, the demand side that will save money and develop. Demand sectors could contribute to flexibility and systems efficiency while receiving quality. These opportunities however need time to mature since they involve a paradigm shift in many sectors. Therefore, it is wise to get started on the interactive dialogue and long term integrated planning.

This section will highlight why the demand side plays a crucial role for advancing these sustainable energy targets in Africa.

A. Access

The need for private sector investments in the power supply sector in sub-Saharan Africa is grand. Off-grid supply as well as mini-grids will have to be part of the solution alongside with grid expansion. Business models for a commercialisation of sustainable cooking are much needed.

The demand sector can act to minimising capex (Capital Expenses) risks, if they agree to bear some of the capex risk through business agreements.

For maturing the off-grid sector, it is advised that institutions act as buyers of energy services and encourage a separate asset owner (fully or semi-private) to provide these services rather than buying assets, such as diesel gensets or solar PV panels, to secure their energy needs. This way service providers are nudged to invest. Useful business models include variants of leasing and Build Own Operate and Transfer.

Being a private investor in rural energy systems in sub-Saharan Africa involves risks of different kind. The customers' actual ability (purchasing power) and willingness to pay is one central factor conditioning the projected cash in-flow and financial viability of the investment.

The number of customers that can be served and their perceived value of the service will be important for the supplier's income from revenues. This includes reliability of supply and minimized power outages. It has also been shown that access to energy is the door-opener for mobile banking and access to credit in remote settlements, which further increases its value.

In sub-Saharan Africa where generating capacity is generally scarce, energy efficiency is paramount for increasing the customer value.

Productive uses of energy is commonly mentioned as a means to overcome revenue risks. More than this, understanding the demand, now and for the relevant time span of the investment - and to provide tailored energy services meeting this demand - is key for viability.

However, in a commercial, competitive market setting, there are limitations to how involved a potential supplier can

[18] There are regional centres for Renewable Energy and Energy Efficiency: SACREEE, ECREEE and EACREEE.

be upfront. Therefore, it is beneficial if the demand side can be backed to present and specify their energy needs. The demand side, however is mostly very complex and includes a variety of partners, aspects and priorities. Initiatives that aim to aggregate and conceptualise demand sectors can therefore unlock scalability. Initiatives can be from branches, business associations and from governments, thereby nurturing, enabling or promoting diversification.

In simple terms, non-dispatchable renewable energy-based electricity suppliers would be better off if loads were stable over time, i.e. without peaks, and nil electricity losses, so as to achieve the maximum utilisation of their investment in supply, transmission and distribution. The cash in-flow would then be maximised and what is more; it would be predictable.

Securing cash revenues is the reason why demand side management activities are is so important for suppliers. In isolated systems, demand side management is even more important. Especially if the generation is from renewable energy technologies, where the investment costs normally are high and fuel costs negligible.

The private supplier may be better of having a spread of customers in different sectors rather than relying completely on one economic sector. For this reason, while each demand sector can support the articulation of needs and contribute to a sensible power outtake, it is not advisable that sectors expect power suppliers to invest on an exclusive basis, for one single value chain. It is better to let the supplier expand and secure viability if required.

Moving forward, cooking should as well be regarded an integral part of domestic dwelling design and be included in the district energy planning, rather than being detached and continuously shaped based on the traditional solutions.

It will make a huge difference if the demand side helps organise and support the high utilisation rate and revenue collection.

The resources and capacities of district governments are however usually meagre. Often their responsibilities have increased immensely due to deregulation and decentralisation of numerous sectors, while staffing may be limited to a single person caring for all budgeting, planning and procurement. Capacitating the district governments is key. In addition, economic sectors or industry branches can proactively engage to manage the demand in spatial or temporal terms such that the energy outtake, revenue and shared value iare maximised.

Through conceptualisation of "proactive demand management", concessional climate finance in the form of soft loans, guarantees and granting can be channelled to such business models where demand is aggregated and bundled, and, as such, provide a buffer to cover up for the revenue risk.

B. Efficiency and optimisation

Energy efficiency is the key to driving incremental reductions in energy intensity. It is one of the few "no-regret" policies that can offer a solution across challenges as diverse as climate change, energy security, industrial competitiveness, human welfare and economic development.

Increased energy efficiency allows existing and new infrastructure to reach more people by freeing up capital resources to invest in enhanced access to modern energy services. Similarly, energy-efficient appliances and equipment make energy services more affordable for consumers – residential, commercial and industrial.

There are important synergies in how access and efficiency manage to address common development objectives. Modern energy services are more efficient than traditional biomass and waste in open fires, and the acceleration of energy access will contribute to a more rapid reduction in net energy intensity.

On a life-cycle cost basis, most energy efficiency opportunities are characterized as having "negative cost": in other words, the savings from reduced energy consumption over the lifetime of the investment exceed the initial cost.

However, it is important to balance this view of the benefits against the many barriers and distortions that can lessen the financial gain and make energy efficiency hard to capture. The cost of capital, taxes and subsidies all matter in determining the attractiveness of an investment. ABesides, transaction costs such as programme and administrative costs can significantly reduce the potential savings on offer.

In light of the fast growing demand in Africa, it will be paramount to have demand sectors engaged and informed about energy efficiency.

African countries need to build and strengthen their capacity to implement effective policies, market based mechanisms, business models, investment tools and regulations with regard to energy use.

A widespread uptake of energy-efficient electric equipment and efficient lighting will be crucial in both the industrial and the non-industrial sectors.

Optimizing a system, process or whole building is however more impactful than opting for efficient appliance efficiency alone. Optimization is about the avoidance of unnecessary demand for energy.

Avoidance – Shift – Improve is a key for systems optimization, such as for transport systems or for industrial processes, process industries or manufacturing industries.

For buildings, the way buildings are placed, the building envelop construction, the orientation of windows and other design features are important and can significantly minimize the resulting need for comfort cooling and artificial lighting.

Clear and structured policies give political transparency, attract investors, provide a possibility to follow up, review and amend development trends and, as such, also open for cooperation with others.

The ability of Africa's cities and district governments to cope with continued rapid growth will be in question given the ubiquitous weakness of urban institutional and infrastructural capacities.

C. Flexibility

In power systems with a high degree of variable renewable energy, a downside is that power may be produced when not needed or not produced when needed. For power producers there will be costs (or outstanding revenues) as a consequence of curtailment of supply or costs for storage to avoid curtailment.

If demand in power systems can be shaped such that it contributes to increasing the system flexibility, these costs can be reduced.

Loads that can be made flexible include for example industries and public services that are not time sensitive, like pumping water into reservoirs, water desalination plants, fertilizer manufacturing and many other industrial processes that can be designed to use energy when it is available in abundance.

Battery charging is perhaps one of the end-uses who's flexibility can intuitively be understood. In future years, electric vehicles and hydrogen fuel cells charging may become an important part of building flexibility into the grid.

Also public lighting, building comfort cooling systems, and IT systems can increasingly build in flexibility and in principle be used to shade load through slightly "dimming" or reducing fan rotation speed when required.

Implementing local-scale, smart grid technologies can contribute to building long-term resilience within the national grid and off-grid technologies can alleviate demand pressures on national grids.

Energy transition in sub-Saharan Africa will most likely therefore involve several supply options and embedded solutions in the built urban environment as well as a variety of off-grid supply and mini-grids in the rural areas.

Energy end use sectors could proactively optimize energy demand and contribute to power grid flexibility. End-users could contribute to establishing storage for buffering excess electricity or, as far as possible, agree to using electricity when available. Planners and designers that could influence are for example district governments, town planners, architects, industry branch associations, agricultural cooperatives, public sector planners as well as private economic sectors and industry.

D. Attracting finance

For financing the African energy transition, private capital will be required alongside with public. When opting for sustainable energy solutions, costs generally shift from low capital expenses (capex) and high operational expenses (opex) to high capex low opex. This in turn moves the risk towards the investor.

Investments in the energy sector are often subject to project financing and Special Project Vehicles (SPV's). Ring fencing (i.e. …) the investment such that it also entails the end-user and the opex part of the structure will help finance the energy system transition.

In a given system, nation, district, business branch or single household, if the savings in operating expenses can be re-directed towards covering the forelaying and future capex for investments in supply, this would be the most straightforward.

However, there can be challenges to source the initial capital and also in redirecting the savings, because of settled agreements and divided responsibilities.. In developing countries in particular, the access to capital can be challenging as well as the cost of capital, which severely limits the opportunities.

Integrated and mindful planning of a climate resilient and low emission energy system including a plan or fund for reinvesting savings accruing over time will help attract private investors as well as different concessional financing streams, such as development aid, and climate finance.

The worlds industries strive to green their production. Therefore, affordable, reliable green electricity is becoming increasingly valuable to them. Offering green electricity in a comprehensible manner will therefore be an opportunity for settling agreements with large customers and as such contribute to the horizontal diversification of economies in Africa.

Climate adaptation funding can also be directed to energy access, provided that the use of the energy supports adaptation. This would increase the amounts available for the most vulnerable people.

E. Conclusions

Sectors that can contribute to the optimization of energy use in Africa already lag behind. Strategies and goals are not formulated, district governments are not resourced, branch organizations and voluntary regulations have not been designed and students are not trained to optimize energy use.

This paper aims to message that strategic planning of energy use have to be given priority. Each of these sectors can argue that there are other more central concerns for them, and maybe the energy cost is not even significant in the overall annual budget or turnover for some. Still, it is them who use the energy and who can influence that African energy systems become sustainable.

Supporting higher system load factors through demand management will increase viability in off-grid supply.

Sharing the capital expenditure risk is a way in which energy demand and supply sectors can cooperate for system efficiency.

Offering flexibility is a way in which energy demand sectors can help system uptake of variable renewable energy.

Managing and bundling demand is a way in which scattered end-users can help attract finance.

Requesting green electricity, is a way in which grid connected institutions can facilitate that their services and products contribute to sustainability.

VII. Approaches to Enhance the Process of Needs-Based Energy Systems Design

Transformational planning and programming is a driver for paradigm shifting pathways and energy transition in Africa. Visionary planning will be a basis for a transition, including pipeline development (i.e. ...), market regulation, legislation, policy, financial incentives, procurement guidelines and voluntary code of conducts. Visionary planning will guide inclusiveness and innovation processes.

Data and statistics about African energy end-use. Mapping energy use in major end use sectors will be instrumental for planning ahead. While the integrated planning approach involves a complexity of factors and data including social/ economic and natural resources that may or may not be available at national, or sub-national levels, energy data can mostly be achieved by proxy, given the net zero nature of energy balances.
Utility data on energy generation complemented with data on imported goods and fuels, may constitute a sound basis to be further refined. The African Continental Free Trade Area (AfCFTA) that finally took effect on **January 1, 2021** can be facilitating to streamline information on traded goods.

Typically, it can be required inventories to complement data based on imported goods, fuels and assets.
Foreign investments, that have occured in many infrastructure sectors in Africa, points at an important aspect of the data mapping and inventory, because imported equipment may have been integrated to the complete offer. For example in the real estate sector it is common that contractors source equipment and materials based on their origin countries' legislation, praxis and contractual
IT technology has over the latest decades changed the way data-collection, assessment and information is possible. Energy end-use can be measured independently from the suppliers' records and provide real time data. For all the modern IT solutions however energy supply is a prerequisite. This is a strong argument for why people in remote areas need access to energy for their preparedness to deal with global impacts as well as for voicing their views for shaping a sustainable infrastructure.

A. Integrated planning

Integrated planning and systems optimization in different major end use sectors can include scenario building, risk assessments and can entail modelling of spatial and temporal variables such has land use, migration and current infrastructure (trade corridors, ports, roads, power grids, cities and town ships).

Integrated planning is not a simple task and requires cross-sectoral, cross-boarder engagement and leadership. This paper however highlights that the net primary energy aspect and its associated GHG emissions needs to be at heart of these exercises because of the very central importance the energy sector has in climate policy.

Long term integrated and cross sectoral planning will strengthen policy coherence and cross-institutional coordination. National adaptation and mitigation plans would benefit from such strategic and implementable planning for low emission, climate resilient and sustainable energy services.

Successful long-term planning builds on scenarios that illustrates different risks and possible mitigation strategies from a non-energy point of view, but where energy is also of fundamental importance.

In the health sector for example, knowledge about the consequences of climate change, disasters, or pandemics such as Ebola or the COVID-19 pandemic, helps mitigate the same [12]. This knowledge need be accessible at different levels, including at the level of the most vulnerable people. Therefore, information systems are pivotal. Information can include advanced satellite data, predictions/forecasts and instant updates, but it can also include processed information that converges experience, risks and mitigation strategies (such as advice for washing hands). Above all, energy access will be paramount for as well data collection as information spreading.

In the food-energy-water nexus, integrated planning entails land use, as well as ground water preservation, eco-systems management and natural resource preservation. Long data series and trends are required, that includes climate change, eco-systems change, and population change.

Long term integrated planning is paramount for the transport sector, urban, inter-urban, and regional alike. Trade patterns, urban sprawl and form will influence what transport systems are the most sustainable. Energy use in the transport sector is a very large part of the total energy use in Africa, and still largely road-bound, fueled by gasoline and diesel.

Shifting towards more transit-oriented transport with electrified public transport backbone, more alternative (non-fossil) fuels and a more electric vehicles in the car fleet will be essential. All these changes will have an impact on the energy systems planning too [11].

Energy system planning will need to incorporate end-use plans for its master-planning and optimization and therefore shall rely on assessing the various end-user sector plans. The more elaborate the energy needs assessment is, and the more it can be open to alternatives that may support the entirety, the more sustainable the energy planning will become.

Power grid extension will continue to be an important back bone throughout Africa, but also decentralized and off-grid solutions. Prospects of having decentralized isolated, yet grid compatible and eventually grid connected power supply are grand, also in urban areas.

There are many applications where a decentralized back-up power supply for public services, industries or vehicle charging could be instrumental and run in island mode or be grid-integrated depending on the system load situation. Management and optimization of such solutions require real time data and new innovative business models.

B. Pipeline development and investment prospectus

Stemming from an integrated planning, it will be important to also support a pipeline development and present investment prospectuses within different sectors. These are mostly "projects" suitable for project finance and need be designed for viability.

In most infrastructure sectors, there is a need for concessional funding to be blended with private capital. A project pipeline that is compatible with the long-term, sustainable and integrated planning will be a central step towards attracting and structuring finance for bankable projects.

The project pipeline will demonstrate opportunities for local commercial banks and finance institutes along with international funders that would otherwise not have been investing in the sectors.

Without a plan and a pipeline, there is a risk that any potential investor will perceive risks to be too high. Without a strategic plan it can also turn out that investments contribute adversely to long term sustainability.

Established examples of pipeline development in the African energy sector include energy supply (independent power producers, IPPs) and to some extent mini- and micro grids, off-grid.

There are however many more possibilities to develop project pipelines for projects that integrate energy and industrial energy efficiency, sustainable agriculture, sustainable water treatment, urban services (energy, waste management and recycling, health services), information and transparency (land rights, asset ownership, district plans, market access, trade), transport and route planning, pre-cautionary health services, vaccine cool cain and more.

C. Market regulation and policy

Alongside with a project pipeline it is instrumental to enable the market through practical regulations. These regulations can also nudge the market towards sustainability.

Ways in which energy end-use sectors can use market regulations and policies to support the energy sector transformation include to lessen fossil fuel subsidies.

Fuel subsidies are commonly applied in many sectors, but most notably they are designed for the transport sector. Other market regulations that can be used in the transport sector include nudging transport route planning, pricing, tax, access control and policy to increase public transport ridership.[19]

Regulations can be punitive and selective, aiming to phase out specific technologies, chemicals or fuel types. These regulations will stem from sector expertise and often international best practice or local variants.

In terms of energy related regulations, standards for fuels, engine types, types of appliances can be given. Such regulations will be developed as part of the end-user sector regulation but will overlap with energy systems regulations as well. For example, the Electricity Act in each country will have rules and regulations pertaining to loads that are connected to the grid in terms of limited accepted power factors and frequency control.

Regulations will typically entail standards and branch codes, for example building codes, asset classes on vehicles, machines and tradable goods. Regulations can also for example regard compulsory waste management and recycling or matters related to safety and health. Regulations can be restricting or conditioning imports or retail. There can be requirements on testing and verification of quality.

In the area of off-grid electricity supply and energy service provision, regulations are required for this sector, including land-rights, provision of licenses to generate electricity, tariff-setting. To enable financial viability in the off-grid sector, is is instrumental that possibilities that integrated services beyond power supply can be allowed, as well as common loads rather than individual. Traditionally, electricity acts have rather aimed to regulate that suppliers should not be influencing or controlling the customers' choice of appliances and a customer that "shares" connections with his neighbours has been illegal.

Regulations can be mandatory or aim to spur competition, asking for performance. In the area of energy and specifically energy efficiency, Minimum Energy performance Standards (MEPS) for single products have proven to be very useful. Many times, international standards can be developed, albeit with variations for e.g. ambient temperature, hours of daylight, power grid frequency or other. More complex types of energy end use – such as manufacturing processes or domestic dwellings - are more difficult to approach from a global perspective because they are more dependent on local culture, specific processes, national legislation and so forth.

D. Procurement guidelines and voluntary praxis

Beyond legislative market regulations, voluntary branch praxis and code of conduct can be powerful and can be referred to in, for example, procurement guidelines. There are many examples of such branch quality measures in the building sector but also in e.g. off grid power supply.

Industrial branches or sectors can themselves develop roadmaps to phase out high emission industrial processes, or can also be nudged, to do so through Market Based Instruments. Market based instruments can also be a way forward to foster a new set of business models or technologies, and will be discussed below.

1) Procurement guidelines

Public authorities can adopt green public procurement standards. Sector ministries or chambers of commerce can support the establishment of praxis that can also be used in public procurement, for example by coordinating procurement policies for commercial electric vehicles.

Sectors that rely on sourcing products, materials or services, such as the construction industry sourcing concrete, can foster alternative feedstocks. Important materials that have large global impact on GHG emissions include steel, cement and some chemicals such as fertilizers for the agricultural sector.

Sourcing "green" electricity can be included in such code of conduct, and, this way, industry branches will contribute to pushing the power utilities towards offering green electricity as an option.

For energy end-use sectors, public or private, the main strategic aspects for technology-neutral and feature based assessments of investments that influence the energy system are out-lined below.

1. Signal a preference to buy green electricity from the power supplier, select green electricity from the utility if it is offered.
2. Avoid non-sustainable energy supply, i.e. fossil fuels and non-sustainable biomass for cooking heating and electricity generation.
3. For investments in on-grid power generation, back-up power or mini-grids, apply LCOE-calculations, or adjusted LCOE to reflect system conditions as a base for presenting incremental cost. Be transparent on fuel costs including subsidies and taxes.
4. For other ring-fenced, project financed investments including systems and services, apply minimum Life Cycle Cost calculations (LCC).
5. Apply building labelling schemes if available. Rent "green building" offices if possible.
6. Apply minimum performance standards on single products/appliances in the system, including but not limited to energy efficiency and Minimum Energy Performance Standards (MEPS).
7. Prioritize/select firms that have waste management (following the polluter pays principle).
8. Prioritize/select firms that have sustainable logistics/transports for establishment, service and maintenance, including the after-market.

Minimum Energy Performance Standards (MEPS). African markets can request high quality products just like the rest of the world, rather than being a dump market. In SSA (Sub-Saharan Africa), 22 countries have just recently agreed on a set of common lighting MEPS standards and are working on MEPS for cooling appliances as well. Before this, single countries, notably South Africa and Ghana have had MEPS for different products. However,

[19] Missing remark on public transport

with the porous borders, unregulated trade, and insufficient compliance and control, these single country regulations were not significantly changing the game.
The International Energy Agency advise that Governments should implement minimum energy performance standards (MEPS) which incorporate a doubling of the average energy efficiency of key products by 2030 in line with the Super-Efficient Equipment and Appliance Deployment (SEAD) target.
MEPS is a very powerful tool available to policy makers. MEPS will need to be upgraded faster than in the past (preferably annually) so as to ban sales of the most inefficient appliances and shift almost all sales to the best available technology by 2030. Global co-operation on high efficiency appliances and cooling equipment could reduce costs for consumers by facilitating co-ordination of MEPS and driving innovation.
For energy end-use sector leads that wish to act faster it is advised to use MEPS and standards that are applied in the adjacent region or globally, e.g. SEAD https://www.superefficient.org/efficient-products and Global Efficiency Medal e.g. for motors: https://superefficient.org/motor-awards, U.S. Energy Star https://www.energystar.gov or the European Eco-design https://ec.europa.eu/growth/industry/sustainability/ecodesign_en . (Note that local adjustments may be required.)

Investments need be assessed on their general quality and sustainability to avoid investments in sub-optimal solutions. Neither product standards nor system requirements will suffice alone. A combination is required.

2) Market based instruments

There are prospects for increased energy efficiency and system flexibility through Market Based Instruments in Africa, as trade and transparency increases [13].

Setting direct demands on energy efficiency measures is easy as long as few actors have large responsibilities and thus can create their own solutions for execution and financing within their regular operations [13].

A type of Energy Performance Contracting (EPC) can be supplied by Energy Service Companies (ESCOs). Worldwide, buildings and the real estate sector has been at the forefront for different forms of energy performance contracting. driven by climate policies and least cost planning. ESCO's may be booming in Africa, but so far has not been broadly used.

For more scattered energy end-users, yet with more complex usage than mere appliances or single products, bundling based on a common sector's branch praxis will be instrumental for creating such market-based instruments. For example, dairy industries, horticulture industries or leather industries can organize themselves voluntarily in order to foster a branch praxis and code of conduct. Also service industries, such as the tourism industry can adopt branch praxis and set ambitions. In a way, ironically, the sector lines up to be more easily regulated, which is not uncommon since it helps the sector itself to increase quality, effectiveness and growth.

For commercial ESCO service providers, it is often rational to combine more than one energy efficiency measure in a package to be able to provide cost efficient and financially viable services with a minimum of external support. What can be saved through one measure can be reinvested in the next.

From a policy perspective therefore, once appliance MEPS have been applied, it is instrumental to soon probe for performance-oriented programmes. While it is recommended to start off with a few schemes tied to products, it is advised to move on to supporting more complex energy service interventions within a few years in order to have energy service companies established and acting on the market before the opportunities of easy interventions, with short pay-back periods, are depleted.

There are two main schemes for EPC, one involving 'shared savings', which implies that the performance risk (i.e. uncertainty of future energy use) is split between contractor and customer. The other, referred to as 'guaranteed savings', implies that the contractor assumes the entire performance risk [5].

E. Inclusiveness and Innovation

Branch based bundling of energy services is further a key to inclusiveness and innovation. A voluntary code of conduct may aim to master community adaptation and may include behavioral aspects and gender aspects. As such it will facilitate to build-in gender sensitive and social positive frameworks for the service provision. Such inclusiveness will enable community-responsive policies, frameworks & practices and will be a basis for public/private (or private/private) partnerships that can increase the viability of investments.

Having a structured dialogue around a specific service need, for a specific context will lead to a better understanding of needs and will be instrumental for identifying information gaps as well as useful advisory and extension systems. It will also contribute to job-creation.

Inviting the end-users to a dialogue and innovation process will be a key for African sustainable development and energy systems transition.

For small and scattered users of energy the concept of catalytic procurement increases the possibilities for a viable energy service supply, if they are supported to form an aggregated customer group. A catalytic procurement scheme is a complete tendering process, with the purpose to support and speed up the development and market introduction of a new technology or service.

The aim is to get new products, systems, processes or services that satisfy the market demand better than those that are already available on the market. Variants of catalytic procurement are for example pre-industrial procurement that has been used to foster the supply of electric vehicles and mobile vaccine cool-chain.

Catalytic procurement also leads to increased know-how, increased capability and attention around the demanded product or service. It serves at co-designing delivery systems to meet user needs. In for example the food sector, the process facilitates in identifying key leverage points for catalysing high-impact adaptation & mitigation in sustainably productive food systems. The catalytic procurement process is broad and it is nurturing demand and supply in parallel. As such, it goes beyond what private sector suppliers can normally bear with their T&D and marketing resources.

F. Adopt or innovate

For innovation programs and financing of innovation, it is often referred to Technology Readiness Levels. An example of a TRL scale can be based on the European scale, which entails Feasibility Testing (TRL 1-3), Technical Development (TRL 4-6), Demonstration of Technology (TRL 7-8) and Commercialisation (TRL 9).

Transferring renewable energy technologies for sustainable development in developing countries, currently have a high focus on the latter stages in the TRL spectrum , i.e. adoption and demonstration as well as commercialization and acceleration.

Prospects for innovation around needed energy services, on the other hand, should not be underestimated. For example, areas such as agriculture, food industry, housing and construction industries are based on local features.

Generally, at the feasibility testing level, there are public grants and to some extent corporate funds depending on the branch. For technical development, already laboratory testing and different test-bed environments cost considerable amounts of money and it is common with private sector contributions, and often risk capital. For example, a technology firm may achieve equity funding for testing through attracting risk capitalists. For infrastructure testing and demonstration, it is normally difficult to perform dry-run tests, so it is often required that the public sector or large private firms puts a stake in testing and demonstration. In the commercialization stage, the amount of public financing is kept as low as possible.

VIII. Conclusions

Demand sectors will benefit from being proactively shaping the energy system. Traditionally, the demand side has been mere users of energy and utilities had limited incentives to seek for efficiency measures in the demand side. Moving ahead, energy demand sectors will be instrumental in that they can offer system flexibility and load optimization. Africa is exceptional in the way so many new energy end-use sectors are yet to evolve. Therefore, prospects for innovation and market based instruments are significant.

Demand sectors need urgently to understand this new era in which their planning ability, procurement ability and ability to foster innovative processes for shaping sustainable energy services will be decisive of how Africa can reach the countries’ targets for sustainable energy supply systems with access to all.

Adopting solutions that have matured in other parts of the world is important but not sufficient – locally anchored innovation and leadership for integrated planning are required..

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Flexibilization of the sustainable energy supply in Ghana : a contribution by waste to electricity conversion

Satyanarayana Narra
Dept. Waste and Resource Management, Faculty of Agriculture and Environmental Science, Universität Rostock. Germany
Deutsches Biomasseforschungszentrum (DBFZ), Leipzig,
satyanarayana.narra@uni-rostock.de

Edward Antwi
Dept. Waste and Resource Management, Faculty of Agriculture and Environmental Science, Universität Rostock. Germany
edward.antwi2@uni-rostock.de

Vicky Shettigondahalli Ekanthalu
Dept. Waste and Resource Management, Faculty of Agriculture and Environmental Science, Universität Rostock Germany
vicky.ekanthalu@uni-rostock.de

Mona-Maria Narra
*Dept. Waste and Resource Management, Faculty of Agriculture and Environmental Science, Universität Rostock.*Germany
mona-maria.narra@uni-rostock.de

***Abstract*—Ghana has one of the highest access to electricity in Sub-Sahara Africa. However, according to the World Bank about a third of rural communities are without access to power, while only 20% have access to modern cooking fuels. Ghana's economy is heavily reliant on fossil fuels to meet its electrical energy demand and renewable energy alternatives play a very marginal role despite the availability of abundant renewable energy sources. Regardless of the government's efforts to integrate renewable energy into the countries energy mix, the current role of renewable energy in Ghana's electricity generation mix is marginal. On other hand, Ghana as a developing country in Africa, is facing major problems concerning waste management due to increased population growth and urbanisation. In this concern, there is a great need to match and modernise the energy supply in Ghana with a flexible demand-driven system. To investigate and demonstrate the flexibility of the energy system, a pilot demonstration plant is currently being built in Ghana under the Waste2Energy project. The plant demonstrates hybrid energy-producing pathways that are tailored to fit the regional scenario with greater intentions to be used as a model plant that can be implemented in other West African countries in the upcoming years. The current paper aims to demonstrate the importance of the Waste2Energy project towards improving renewable energy and combating waste management problems in Ghana.**

Keywords*— *Renewable energy, Waste management, Hybrid energy, Waste2Energy, Energy supply.

VII. INTRODUCTION

Ghana, even though still a developing country, is one of the fastest-growing economies in Africa. Over the last 30 (1990 - 2020) years, Ghana has posted an average gross domestic product of about 5.3% per annum and 6.3% in the last 15 years both of which are higher than the average growth rate of about 3.4% and 3.6% respectively for the entire Sub Sahara Africa over the same period [1]. The rapid growth rate has come at a huge cost to the environment. Over the period from 1990-2016, Ghana's carbon emission stock has increased by 66.4% from about 28 $MtCO_{2eq.}$ to about 42.2 $MtCO_{2eq.}$ Greenhouse gas inventory of the country point to the energy and waste management sectors as one of the main drivers of greenhouse gas emission apart from the Agriculture Forestry and Land Use (AFOLU) sectors. Together they account for nearly 43.1% of all greenhouse gases emissions in the country [2]. This is largely due to the over-dependence of the country on fossil fuels to drive the economy. Demand for fossil fuels has doubled over the last 15 years and is likely to keep growing. At the same time, Ghana, like most developing countries, has a linear economy where waste is largely untreated. The transition to a circular economy is in its infant stage. For Ghana to advance its economy to a circular one, the energy sector and the waste management sectors should be the pivot on which the transformation must revolve.

Ghana is endowed with plenty of renewable energy resources. When utilized sustainably, these resources have high efficiency to fulfil the energy demand of the country. The fifth assessment report of IPCC, the United Nations' Intergovernmental Panel on Climate Change stresses the need for finding alternative energy, especially for those developing world which is still using old-fashioned fossil fuels [3]. Additionally, the energy sector is the prime factor in achieving both the Paris Agreement on Climate Change and the 2030 Agenda for Sustainable Development. In concern to the decrease in fossil fuel reserve and to combat global climate change, several developing countries, including Ghana, are searching for potentially sustainable and renewable energy alternatives to meet the increasing demand for energy [4]. Ghana, with the adoption of United Nations Sustainable Development Goal 7 (SDG) targets to ensure access to affordable, modern and reliable energy services throughout the country. This target also presents a greater challenge because Ghana as a country still relies mainly on traditional biomass as a primary source of energy. Almost 50% of Ghana's overall energy use is produced by extremely inefficient combustion of the traditional biomass as fuel-wood and charcoal for cooking and heating purpose. The conventional charcoal production practice in Ghana is not only inefficient but also has major potential to contribute to Ghana's deforestation problem and significantly affecting the health conditions of the poor rural and urban population. Nevertheless, Ghana has greater possibilities for renewable energies and waste to energy recovery potential which remains hugely underexploited.

For the conversion of renewable energy potentials into actual energy, the government in 2006 set a target of achieving 10 per cent of renewables in the electricity mix by 2020 [5]. The Government of Ghana in 2010, as a medium to the long-term solution, announced the Renewable Energy Law (Act, 832) [6]. One of the primary goals of the Renewable Energy Law is to increase the share of modern forms of renewable energy to 10 % in the total energy mix. Unfortunately, as of October 2018, the renewable energy in the country's electricity mix was less than 2 %. The failure in meeting the target was due to a number of factors which mainly includes the policy issues surrounding the transition to renewable energy [7]. However, the government of Ghana has extended the target of incorporating 10 % renewable energy in the total energy mix by 2030 and also has come up with a renewable energy master plan to facilitate the achievement of the policy target [5].

At the same time, waste management is a serious problem in most African countries particularly in the cities due to the generation of huge amounts of waste as a result of the rapidly increasing urban population. The waste generation is anticipated to increase exponentially in the near future [8]. Further, the modernisation in the agricultural sector is also anticipated to contribute significantly to the growth of waste produced in Africa [9]. According to the comprehensive study carried out by Bello et al. (2016), globalisation has tremendously increased waste generation in Africa and therefore, an urgent need for an intensive effort to salvage the trend.

Ghana has equally faced its share of problems concerning waste management due to increased population growth and urbanisation. As a result of urbanization and increasing population, concerns on waste management are raising in two big cities of Ghana, namely Accra and Kumasi. According to Bawakyillenuo and Agbelie 2014, Accra city alone produced 2,800 metric tons of municipal solid waste per day of which 2,200 tons is collected and the rest 600 tons is left in the city unattended. Several studies conducted in Ghana have shown that there is a great potential for energy generation from waste produced in the country [10, 11, 12, 13]. Currently, Ghana's economy relies heavily on petroleum products as the major source of energy. There is yet very little part in the energy mix of the nation that includes sustainable renewable energy sources. Against this background, many researchers are progressively realising that waste to energy generation could be the most sustainable and practical solution to the twin problems of waste and electricity crisis management in the country. Waste to energy approaches will not only serve as a sustainable waste management strategy but also has the potential to reduce greenhouse emissions while opening up new opportunities in the transport sector through the use of biogas as a vehicle fuel and reducing national grid peak load. The predominant aim of this paper is to portray the tailor-made solutions concerning the ongoing waste to energy project (situated in the Atwima Nwabiagya Municipal Assembly in the Ashanti region of Ghana) that is anticipated to tackle the problem associated with waste and power management in Ghana by harnessing waste and renewable energies into the nations energy mix. In future, scientific data gathered from the plant will be used to scale up the plant and draw up business case models to drive its replication in other communities. The project also seeks to kick-start and drive the transition from a linear economy to a circular economy with the demonstration of the pilot waste to energy hybrid plant, transfer of technology and transfer of knowledge and skills.

VIII. Ease of Use

A. *Overview of the energy mix in Ghana*

Electricity/Energy is one of the major indispensable elements from the economic prosperity of any country; serving as a foundation on which every sector of a countries economy thrives. Accordingly, the living standards of the people in Ghana are closely dependent on energy security. However, more than 50% of Ghanaians still use extremely inefficient combustion of the traditional biomass as fuel-wood and charcoal for cooking and heating purposes [14]. The total energy consumed in Ghana in 2019 is accounted to be 7,974.5 Ktoe. The total primary energy supply in Ghana was 11,159.0 Ktoe in 2019 increased by about 2.7 % from 10,852.0 Ktoe in 2018. 38.36% of the primary energy supply was produced by using petroleum products, followed by the biomass in the form of firewood and charcoal at 37.77% and 23.84% was from natural gas and hydropower (see Table 1) [15]. The domestic energy demand is highly dependent on the consumption of biomass (firewood and charcoal) and the biomass consumption rate for the production of domestic energy has increased drastically over time (see figure 1).

In the past decade, Ghana's peak electricity demand has been increased by more than 50%; increasing from 1,393 MW to 2,087 MW between 2006 and 2016 respectively [16]. The generation of electricity in Ghana is primarily from hydro and thermal sources. Total electricity generation in Ghana has increased significantly from 7,224.00 GWh in the year 2000 to 18,189.00 GWh in 2019. The share of thermal energy in countries total energy generation has increased to 59.8% in 2019 from 8.5% in 2000. However, the share of hydropower in countries electricity generation decreased from 91.5% in the year 2000 to 39.9% in 2019 [15]. Renewable energy generation has not played a major role in the generation mix of 2019. Nevertheless, since 2013 several initiatives have been taken by Ghana to integrate renewable energy production to diversify the electricity production mix. Nevertheless, this sector is becoming increasingly popular

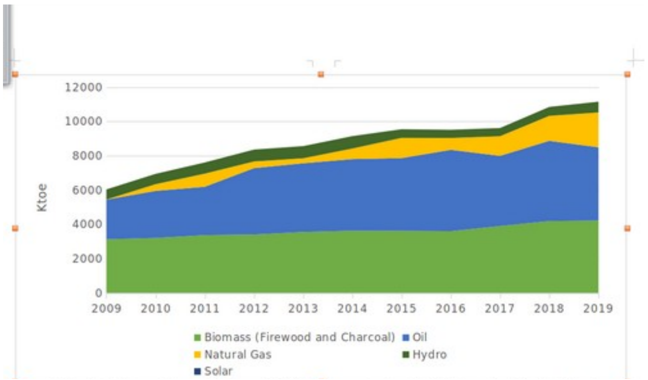


Figure 1. Primary and domestic energy trend in Ghana (Energy commission [15].)

and the renewable energy production in 2019 (42.6 MW) has increased almost 20 times than it was in 2013 (2.5 MW).

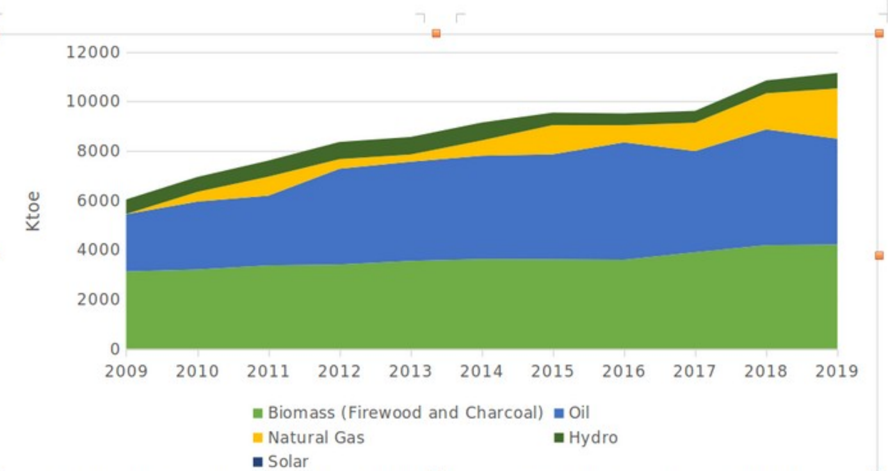
Before 2015, only 2.5 MW of renewable energy produced from a solar photovoltaic plant owned by the Volta River Authority was feed directly into the national grid. Later 2016 there was 20 MW solar plants and a 100 kW biogas energy production facility that was directly integrated into the national grid to boost the renewable source in the electricity generation mix. By the end of 2019, total electricity generated from renewable energy sources constitutes for about 0.3% of the total electricity generated in Ghana. One key missing element in Ghana's generation mix, is the lack of flexible generation options. The overdependencey on thermal and hydro energy sources means that whenever there is a challenge with any of the units a huge amount of energy is taken off grid. This can be catastrophic to industry and residential facilities and could be one of the reasons for Ghana experiencing power shortage. For instance a damage to the West African Gas pipeline in Togo in 2012 led to the serious distruption in gas flow to Ghana's thermal power plant which eventually plunged the country into power crises resulting in load shedding for at least a year [17]. Similarly, perennial shortage in rainfall and evaporation results in lower water levels in the Akosombo hydroelectric dam which subsequently affect the final power output of the dam and thus plunging the country into energy crises [18]. Consequently, due to the lack of flexible generating systems, the power sector end up in crises. Moving forward, Ghana needs to look at the possibility of introducing more generating systems that can support both base load and peak load.

TABLE 1. GHANA TOTAL PRIMARY ENERGY SUPPLY IN 2019 *[15]*

Ghana energy demand in 2019		
Energy demand	***Ktoe***	***%***
Oil	4276.0	38.36
Natural Gas	2036.0	18.24
Hydro	624.0	5.60
Solar	4.0	0.03
Biomass (Firewood and Charcoal)	4218.0	37.77
Total	**11159.0**	**100.00**

B. Waste management situation in Ghana

Using the per capita waste generation of 0.47 kg/day [17], and the current population of 30.8 million [18], Ghana generates about 14,472 tons of municipal solid waste every day, of which only 18.2% [19] is collected and disposed at a designated dumpsite. The remaining are either burnt openly or left uncollected. The major challenge in managing solid waste in Ghana is associated with the collection and disposal process as it is often not effective and labour intensive [20]. The local government authorities in urban cities of Ghana faces major challenges concerning the issues related to proper solid waste management and are often overwhelmed by the volume of daily waste generated [21]. The lack of efficient and well-planned strategies to manage waste is one



application of the concepts of circular economy to convert waste into valuable resources particularly in a developing country like Ghana is urgently needed.

Even though Ghana currently has five engineered landfills, most of them are in a dysfunctional condition [23]. The main methods for waste disposal in Ghana include uncontrolled dumping, controlled dumping, sanitary landfilling, and composting [24]. Open refuse dumps are the most common sight at the perimeter of major urban centres, wetland areas and next to surface water sources. Especially in small towns and rural areas, there is often no waste collection service which in turn leading to uncontrolled waste dumping within the built-up areas causing waste-related health hazards and negative environmental impacts [24]. Currently, the large scale composting of municipal waste mainly takes place in the larger urban areas in Ghana, particularly in the regional capitals. Main composting firms in Ghana are Zoomlion, Jekora, DeCo!, and Eco+ products [25]. The biggest composting plant of Ghana is operated by Zoomlion and is located in Accra (Accra Composting and Recycling Plant). This plant has a capacity to treat up to 600 tons/day and was founded on a public-private partnership arrangement with the district assemblies. Undoubtedly, composting adds value to the waste. However, in Ghana the majority of the collected waste is unsegregated at the source and the composting process must require prior sorting which needs resources (time, finance and labour). Improper sorting greatly affects the quality of compost particularly when it is designated to be sold. In the broader perspective, low-quality compost might cause potential contamination to soil and are likely to cause health risks.

C. Importance of waste to energy generation in Ghana

The concept of circular economy is based on the principles of using waste as a resource. Ghana as a developing country has an urgent need to emphasize on reducing, re-using, recycling and recovering the waste to combat the increasing cost associated with waste disposal, greenhouse gas emissions and generation mix. It has been estimated that shifting to a circular economy by turning waste into a resource could bring about US$1 trillion to the global economy and creates about 100,000 new jobs by 2025 [26]. Similar to most of the developing African countries Ghana faces the problem of huge unemployment, lack of capacities to meet sustainable energy production and difficulties in properly managing the generated waste. It is, therefore, essential to promote the development of their economies by converting waste into a resource for poverty mitigation and to create new sustainable jobs for their citizens. The conversion of waste to energy has gone beyond waste management and is recognised as a crucial element in developing a sustainable, low carbon, resource-efficient economy, and a tool to address power scarcity. The utilization of a wider framework of circular economy in waste to energy creation would help Ghana to progress
sustainable future. Waste to energy can be simply
a process of converting or generating energy from
al and industrial waste, animal manure, agricultural
ts, as well as municipal solid waste, which are non-
. The conversion of waste to energy also enhances
e waste management by avoiding greenhouse gas
which could happen typically when waste is
[12].

generates about 0.47 kg/person/day of municipal
e [27], and with a population stand of 30.8 million
duces about 14,472 tons of waste per day. Ghana

has huge potential for waste to energy industry as the composition of waste generated in Ghana has a comparatively higher percentage of organic materials [12]. According to Miezah, et al. (2015), the municipal solid waste generated in Ghana has biodegradable waste composition ranging between 61-64%. This composition of organic waste indeed shows the potential of Ghana to adopt the technologies of waste to energy. Nevertheless, the success of the waste to energy industry in Ghana greatly depends on capacity building and making the public understand the importance of waste sorting at the source.

IX. The Description of the Waste2Energy Demonstration Plant

The site for the construction of the pilot 400 kW facility is situated in the Atwima Nwabiagya Municipal Assembly in the Ashanti region of Ghana. The key reason for the choice of this particular location was primarily due to the availability of household waste, agricultural residues due to the agrarian nature of the local economy, and the readiness of an off-taker for the generated power. Additionally, the availability and willingness of the community to contribute land (40,000 m^2) in kind was a major factor. The pilot facility is situated on 12-acre land released to the project by the Chief and elders of Gyankobaa. The ongoing plant has a hybridised combination of solar PV systems, biogas and pyrolysis plant. Even though the plant is designed to be a hyrid plant, each power generating unit can be decoupled and generate power into the grid autonomously. This means, when the biogas plant is down for maintenance, the pyrolysis plant and the solar PV plant can still supply power to the grid. Further both the biogas and pyrolysis plants can support both base load and peak load thus bringing in the kind of flexible operating systems that is missing in Ghana's generation mix. Additionally, the three units are integrated such that the power from the solar PV systems will be partly used to power the segregation units as well as the material movement units of the biogas and pyrolysis plants. The heat from the exhaust gas of the pyrolysis and biogas generator will be recovered and utilized to heat the digester such that mesophilic anaerobic conditions will prevail inside the digester. The utilization of the recovered heat will speed up the reaction process leading to higher or improved gas outputs, reduce the hydraulic retention time and make it possible to treat a larger amount of waste than at mesophilic conditions. The excess heat will be used to dry feedstock before pyrolysis. Thus the efficiency of the overall plant is expected to improve while providing the best possible energy recovery pathway from different waste streams such as biomass and plastic waste from the household, industrial waste and agricultural residues in the vicinity or neighbourhood of the community.

The plant will also deploy the best way to provide reliable and uninterrupted power through smart control systems such that there is flexibility to switch from one technology to the other while ensuring the longevity of the various units. Aside from the energy generation, the hybrid system is also planned to explore the possibility of dehydrating the digestate obtained from the biogas plant to produce a marketable dry compost that can be sold as fertilizer to the farming community nearby. Other value additions that will be explored will include biogas sweetening and bottling to be used as a domestic fuel, activated carbon, catalytic cracking to obtain liquefied petroleum gas, light, and heavy naphthalene and other special fuels. These will further enhance the efficiency of the plant and make it more economically viable.

A. *Impact of the Waste2Energy pilot plant*

Aside from the generation of power from the municipal solid waste, the hybrid waste to energy as a sustainable project places a high premium on capacity building through knowledge and skills transfer. The transition to a circular economy can only be succeeded if the Ghanaian population has a good and better understanding of proper waste management. To this end, the capacity building activities have been designed with a bottom up approach where the local communities are engaged in sorting waste at the source. This has been especially proven in Germany, sorting of waste at source is the bedrock of an effective waste management system. Without sorting at the source, the waste fractions in the mixed stream are difficult to efficiently separate into their individual components which in turn makes treatment very difficult and expensive. The integration of the local people also gives the people a clear sense of project ownership. In that, they see themselves as being part of the final solution and not just dumping of technology on them. Further, the pilot plant will be used as training grounds to build the capacity of local waste management actors. This will be started with the host municipality and later extended to cover all municipalities in the country. The purpose is to transfer knowledge and skills to the principal actors in waste management at the various municipalities to enable them to plan well and adopt the best practices in waste management. This will be a continuous activity to ensure that the transition from a linear economy to a circular economy does not only take place at the top but rather the local government structure is well informed and abreast with the state-of-the-art information and have a physical experience of proper waste management through visits to the pilot facility. To ensure that the transition to a circular economy is complete aside from carrying an elaborate state-of-the-art policy review which will inform the policy direction at the national level in favour of green and circular economy, the plant will also serve to train national officers on proper waste treatment. The national officers and policymakers will have first-hand experience through the pilot plant to see the transformation of waste into energy carriers. The plant will also serve as a research and development laboratory for the training of students at the M.Sc and PhD levels. This builds the technical and research skills set needed for continuous learning and adaptation as well as the adoption of the pilot facility. It will also help improve on the design, optimize the process and ensure that future projects of its kind achieve more impact.

The problem of waste management in Ghana is not localized to a few selected communities, rather it is widespread and pervasive in all communities, cities and metropolitan areas. For this purpose Waste2Energy project also provides a solid foundation to make a strong business case and capacity building for similar technologies to be deployed in other communities. In this concern, the country will be segmented into four zones: (i) Municipalities/Metropolitans/Districts – with common waste dumping grounds, (ii) cities and towns – with common waste dumping grounds, (iii) small communities and villages – with a common waste dumping ground and (iv) Off-grid communities. The study will include full technical feasibility to determine the amount, quality, composition, and characteristic of the generated waste, and the potential of the waste to be used in biogas or pyrolysis plant will be determined. Further, the financial feasibility and SWOT analysis will be used to evaluate the strength and weaknesses of the financial models. Based on this analysis, a roll-out plan for future projects will be developed, which serves as a blueprint to guide the future deployment of the hybrid waste to energy power plants which have the potential to be replicated in Ghana and most of the West-African countries.

B. Future perspective

The hybrid waste to energy pilot plant as a model has high replicability. Firstly the model is expandable or retractable in the sense that bigger or smaller capacity plants can be designed. This is very important given the fact that waste generation, in general, is scattered across the various human settlements. Thus the model makes it possible to have decentralized waste treatment units where smaller tailor-fit solutions are provided for smaller communities. Also, even in larger cities, suburbs within the city can have their own treatment plant. Further, the plant can be placed at a demand point where waste is either accumulated or demand for electricity is very high. This way, both the model can be adapted to both central treatment models or decentralized treatment models. Secondly, the model can be replicated easily. Waste treatment is not only a challenge in the urban communities in Ghana. Even though the waste generation potential is higher in urban communities, rural communities also face the same challenge of poor waste management. Thus this model can be replicated in both urban and rural communities. Thirdly, the model also addresses the sanitation problem in Ghana. Most West African countries and for that matter cities all over the world face similar challenges of poor waste treatment. The waste composition and characteristics are quite similar across the sub-regions due to the socio-cultural similarities that exist across the sub-region. Thus the model can be used in several African countries to catalyse the transition from linear to a circular economy and decarbonize the economic development of the respective countries. Lastly, this project will serve a very useful purpose in a region with one of the lowest access to electricity in the world. Communities without access to electricity can use this model to both treat their waste as well as generate enough power to feed their homes and businesses. Additionally, since access to modern cooking fuels is also a major challenge, the different energy carriers will be used to address the overdependence on forestry products as fuel sources and catalyze the transition from dirty fuels to clean and modern fuel sources.

The success and outcome of the Waste2Energy project is not only limited to foster Ghana towards circular economy and development of highly sustainable renewable energy sector.

The overarching aim of the project is to deliver a major impact on the regional renewable energy development in West-African countries by providing the solution to the twin problem of waste and energy crisis by converting the waste into useful energy. This project provides technical guidance to the other West-African countries to adopt and create highly efficient sustainable waste to energy technologies. The scientific data gathered from this plant will be used to scale up the plant and draw up business case models to drive its replication in other communities of Ghana and other West African countries.

X. Conclusion

Ghana's transition from a linear economy to a circular economy can only be driven and be successful if a high premium is placed on capacity building and models that are flexible in the delivery of final products. The Waste2Energy project manifests the possibility of hybridization and flexibilization of renewable energy sources which can be replicated in most of the West-African countries. This project is designed to involve the integration of various technologies such that power from the solar PV can be used to drive some of the units in the biogas and pyrolysis plant as well as the utilization integration of the excess heat from the pyrolysis and power generation units into the digester to improve digester performance. The hybrid waste to energy pilot model serves to deliver flexible energy carriers depending on demand for the final products as well as serve a very important purpose of being a training ground for a bottom-up capacity building approach that transfers skills and knowledge. The model can be adapted and adopted in several locations and can be used to catalyze the transition from a through away society to an environmentally conscious society ready to see waste as a resource than just waste.

Acknowledgment

The authors acknowledge the German Federal Ministry of Education and Research (BMBF) for financing the Waste2Energy project.

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Efficacité énergétique et autonomisation économique des femmes entrepreneures d’activités génératrices de revenus au Bénin

Monique Ouassa-Kouaro
Laboratoire d'Anthropologie Appliquée et d'Education au Développement Durable (LAAEDD)
Département de Sociologie-Anthropologie,
Université d'Abomey-Calavi,
Abomey-Calavi, Bénin
mkouaro@gmail.com

Boni Florent Tasso
LAAEDD, Département de Sociologie-Anthropologie,
Université d'Abomey-Calavi,
Abomey-Calavi, Bénin
tassoflorent@gmail.com

***Résumé*—L’énergie électrique est une ressource indispensable au développement des activités économiques.**

La présente recherche se propose d’analyser l’accès des femmes à une énergie électrique fiable et de qualité et ses implications sur leur autonomisation économique au Bénin. Elle adopte une démarche méthodologique essentiellement qualitative basée sur un échantillon raisonné défini à partir de la technique des itinéraires dans les villes de Cotonou et Parakou. Le corpus empirique, constitué de 32 entretiens individuels approfondis et de 05 discussions en focus groups, a été complété par des données issues de l’observation directe et de l’analyse documentaire.

La triangulation des données de terrain dans la perspective théorique du changement social révèle une meilleure connaissance des déterminants des choix des sources d’énergie électrique en fonction des activités génératrices de revenus (AGR) exercées. Elle démontre que l’autonomisation économique des femmes développant des AGR souffre de difficultés d’accès à une énergie fiable et de qualité.

Mots-clés—énergie électrique, changement social, autonomisation économique, développement durable, Bénin

XI. Introduction

L’Objectif du Développement Durable 7 (ODD7), est de garantir l’accès de tous à des services énergétiques. L’énergie électrique est précieuse dans la mesure où elle permet de satisfaire les besoins vitaux des hommes. L’électricité spécifique pour certains usages, éclairage, froid, information et communication, joue un rôle essentiel dans le développement. C’est pourquoi, la grande préoccupation pour l’accès aux services énergétiques constitue depuis toujours un enjeu majeur [2]. Du fait, des avancées enregistrées dans le domaine de l’énergie, la question de l’accès et du contrôle des ressources énergétiques constituent un enjeu [3] planétaire, mais plus encore un défi dans la réduction de la pauvreté des Africains et des Béninois en particulier. Dans ce sens, U. Bard i[1] soutient que l’électrification des villes, des villages et des territoires, la rénovation thermique des bâtiments, permet de créer de nombreux emplois. Les femmes des milieux urbains et ruraux du Bénin saisissent ces avancées pour le développement de leurs activités économiques en vue de leur autonomisation et de l’amélioration des conditions de vie des ménages. L’objectif de la présente étude est d’analyser les enjeux de l’efficacité énergétique dans l’autonomisation des femmes entrepreneures d’activités génératrices de revenus au Bénin. Dans quelle mesure l’accès et le contrôle à une énergie électrique fiable et de qualité contribue-t-elle au développement des AGR des femmes, et par ricochet au développement inclusif et durable du Bénin ?

XII. Matériels et méthodes

La recherche adopte une démarche méthodologique essentiellement qualitative à visée descriptive et analytique. En effet, pour comprendre les déterminants de l’accès à l’électricité et de leur influence sur l’amélioration des AGR des femmes , le choix d’une approche méthodologique de recherche qualitative s’est avéré important. Un échantillonnage raisonné a permis de conduire la recherche dans les localités de Cotonou (capitale économique du Bénin située dans la région méridionale) et Parakou, (troisième plus grande ville du Bénin située dans la région septentrionale), villes carrefours où l’activité économique est très développée. Les unités de l’échantillon, constitué de femmes menant des AGR, de femmes spécialistes du montage des panneaux solaires, du personnel technique de la SBEE et d’hommes ont été sélectionné(e)s par choix raisonné à partir de la méthode des itinéraires.

Les entretiens individuels approfondis et de groupes, l’observation directe et la recherche documentaire ont été les techniques de collecte des données mobilisées. L’entrevue semi-structurée a particulièrement permis de recueillir des données de premières mains sur les sources d’énergie électrique utilisées et les déterminants (sociaux, culturels, économiques et environnementaux) de l’accès à l’électricité. Elle a également permis d’apprécier les disparités de genre dans l'accès à l'électricité dans les ménages tout comme les enjeux de l’efficacité énergétique dans le développement des activités génératrices de revenus. Quant aux focus group, ils ont été organisés avec des groupes homogènes de 8 à 12 personnes, notamment des femmes et des jeunes, et ont permis de collecter en peu de temps et dans une perspective interactive des informations précieuses. Au total, un échantillon de 74 acteurs (6 hommes et 68 femmes exerçant des AGR) a été approché après atteinte de saturation des données de terrain.

XIII. Résultats

A. *Déterminants des sources d'énergie électrique utilisées selon les activités génératrices de revenus exercées*

L'analyse des données de terrain révèle l'adoption de plusieurs sources d'énergie électrique par les femmes développant des AGR. Il s'agit notamment de l'énergie électrique conventionnelle de l'opérateur SBEE, de l'énergie solaire et des groupes électrogènes. Toutefois, il importe de préciser que l'énergie conventionnelle reste la principale source d'énergie électrique utilisée par près de 67% des acteurs interrogés.

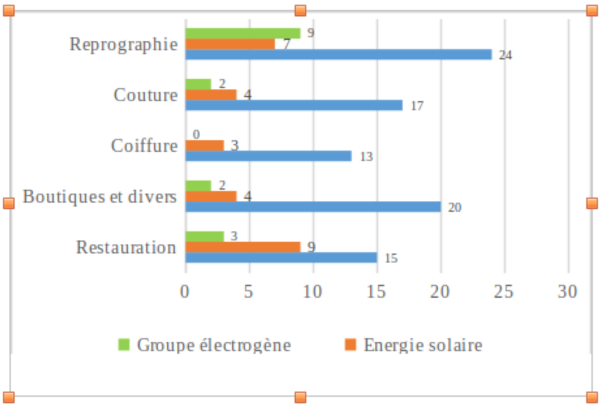

Figure 1: Répartition graphique de la proportion des femmes utilisant les différentes sources d'énergie électrique suivant les AGR exercées

L'utilisation de l'énergie électrique par les femmes dépend particulièrement des activités économiques exercées, de leurs revenus, de la taille de l'entreprise mais aussi et surtout de la fiabilité et de la qualité de l'énergie électrique. Le témoignage d'une femme restauratrice au quartier Gorobaani de Parakou illustre bien ce point de vue :

« *Par le passé, j'avais eu la chance d'utiliser l'énergie de la SBEE, parce qu'on était proche du goudron. Cela m'aidait beaucoup pour mon commerce de vente de nourriture les nuits et même dans la journée pour la vente de glaçons, des sucettes*[20] *et des boissons. Mais, à cause des coupures électriques répétées et prolongées, parfois sur plusieurs jours, que connaissait notre localité, nos activités ont été presque paralysées. Alors pour continuer à satisfaire nos clients, plusieurs d'entre nous, avions fait le choix des groupes électrogènes pour l'éclairage et le refroidissement de nos produits. Mais à cause du coût de fonctionnement élevé et de l'inflation des produits pétroliers, nous avons recours aujourd'hui aux panneaux solaires. Ceux qui utilisent des groupes électrogènes ne sont plus nombreux. Nous choisissons la source d'énergie électrique à utiliser en fonction de la taille du commerce et du coût du dispositif d'installation qu'il faut pour alimenter tous les appareils* » (femme restauratrice, 48 ans, Dendi, Parakou, 2022).

Il ressort de cet extrait d'entretien que la qualité de l'énergie électrique conventionnelle contraint certaines femmes entrepreneures à recourir à d'autres sources d'énergie électrique afin de rendre viables leurs entreprises. Les coupures intempestives, les baisses de tension, conjuguées au coût élevé des factures et aux difficultés d'accès au réseau électrique conventionnel justifient la tendance à la diversification des sources d'énergie électrique observée au niveau des femmes développant des AGR. Les propos de femme revendeuse de divers à Parakou confirment également ce point de vue :

« *Le courant de la SBEE revient cher chez ceux qui le revendent : le kilowatt nous est revendu 250 FCFA. A fin du mois, tu te retrouves avec une charge moyenne de 15.000 FCFA. J'ai dû investir dans le panneau solaire qui me donne de satisfaction du moins par rapport à l'éclairage de ma boutique* » (Femme revendeuse de divers, 55 ans, Parakou, 2022).

Par ailleurs, il ressort que les femmes ont généralement un accès et un contrôle limité à l'énergie électrique qu'elle soit conventionnelle ou solaire. Dans les localités étudiées, l'organisation sociale de type patriarcal confère à l'homme le monopole du contrôle des ressources électriques : la charge de la connexion au réseau conventionnel incombe principalement à l'homme.

Le graphique ci-après présente la féminisation de la pauvreté énergétique.

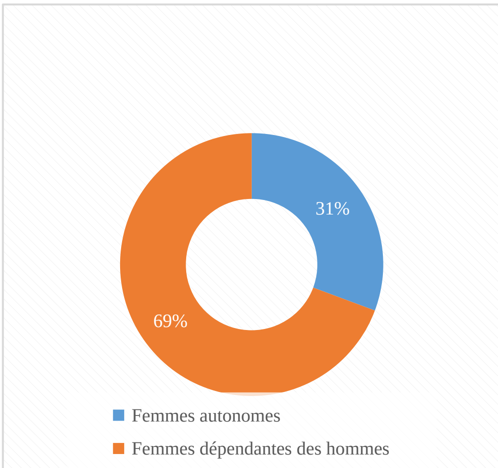

Figure 2. Représentation graphique des femmes autonomes en approvisionnement électrique et celles dépendantes des hommes

De la lecture du graphique, il ressort que seulement 31% des femmes sont autonomes en approvisionnement électrique contre 69 % qui restent dépendantes des hommes.

Cette féminisation de la pauvreté énergétique inhibe le développement de certaines AGR chez les femmes.

[20] Les sucettes au Bénin sont des jus de fruit (ananas, mangues, citron, orange etc…) que les femmes conditionnent elles-mêmes dans des sachets ou gourdes qu'elles vendent à domicile, à des endroits publics de forte affluence ou en faisant de la porte à porte. C'est une activité génératrice de revenu très connue pour être menée par les femmes.

« *Si tu ne connais personne et si tu n'as pas de moyens, tu ne peux pas avoir ton propre compteur. Et lorsque tu négocies avec quelqu'un pour qu'il te vende l'électricité, c'est sur ta tête qu'il réalise ses bénéfices. Dans ces conditions, il est difficile de mener les activités économiques de ton choix en toute tranquillité. Tu ne peux pas par exemple dans mon cas, maintenir gelés les produits comme tu l'aurais souhaité*» (Femme propriétaire d'une poissonnerie, 51 ans, quartier Gah, Parakou, 2022).

Les disparités d'accès des femmes à l'électricité affectent donc le développement de leurs AGR .

1. Efficacité énergétique et développement des AGR

L'énergie électrique est aujourd'hui au cœur des AGR. L'adoption de l'énergie électrique par les femmes exerçant des AGR dépend du coût d'achat et de sa qualité. En effet, plus l'énergie est à un prix accessible pour les femmes ayant une petite entreprise, plus elles l'adoptent. Cependant, avec les femmes ayant de grandes entreprises dépendantes quasiment de l'énergie électrique, l'électricité est adoptée non seulement par rapport à son coût d'appropriation mais également et surtout par la qualité des prestations qu'elles procurent. Des investigations de terrain, il ressort ainsi que la qualité, la fiabilité mais aussi le coûtde l'électricité déterminent son adoption par les femmes exerçant des AGR. C'est ce que nous révèlent les propos de cette restauratrice lorsqu'elle affirme :

« *Il n'est toujours pas facile qu'une femme ait accès à l'électricité dans ce pays vu les garanties qu'il faut donner, le coût de la demande avoisinant 100000 FCFA. Pour les femmes, ce montant est largement suffisant pour lancer une activité pouvant rapporter assez à la commerçante. Heureusement, avec l'évolution de la technologie, il est aujourd'hui possible d'avoir un dispositif solaire pour l'éclairage à moindre coût (5000 FCFA, 10 000 FCFA, etc.). Le tout dépend du pouvoir économique de chaque individu. J'ai pu m'acheter depuis bientôt un an, un kit solaire de 180 000 FCFA qui me permet d'être autonome sur le plan énergétique et d'éclairer ma boutique. Les panneaux solaires nous permettent aujourd'hui de disposer de l'électricité pour l'éclairage à moindre coût et en permanence* » (Propos de D.N, 32 ans, Béninoise, restauratrice à Parakou, 2022).

Il ressort de ce corpus que l'énergie joue une part importante dans l'exercice des différents AGR. Cependant, le coût d'accès à l'énergie conventionnelle est un facteur déterminant orientant certaines femmes à l'adoption de l'énergie solaire pour le développement de leur activité compte tenu de la grande dépendance en énergie électrique.

B. Accès à l'électricité et renforcement de l'autonomisation économique

Un accès fiable à l'électricité est un impératif pour toute économie moderne. L'utilité de l'électricité se fait sentir sur la quasi-totalité des activités d'ordre économique et ses avantages et apports au développement ne sont plus à démontrer. L'électricité au-delà de sa fonction première qu'est l'éclairage joue un rôle remarquable dans l'exercice des activités génératrice de revenus des femmes ; en ce sens où il permet aux revendeuses d'augmenter leur chiffre d'affaires à travers des heures supplémentaires de travail. L'accès à l'électricité favorise ainsi le développement de petits commerces nocturnes et l'animation de petits marchés. Les femmes connaissent de plus en plus de meilleure prestation dans leurs activités et cela se fait ressentir dans leurs ménages. L'adoption de certains appareils électroniques par les femmes dans leurs activités, leurs permet de répondre aux attentes de leurs clients à temps sans grandes dépenses d'énergie. Elles peuvent ainsi s'occuper de plusieurs clients dans la journée grâce à l'énergie électrique qui se présente comme un facilitateur à leurs portées.

C'est dans cette logique qu'une des actrices interrogées affirme :

« *Il y a 08 ans, je ne pouvais pas me permettre de vendre au-delà de19h. Mais depuis qu'il y a eu de l'électricité, mon commerce s'anime jusqu'à 00h et parfois au-delà. Je peux vous dire que mes revenus journaliers ont grimpé (de 10.000F à 50.000F).* » Propos de G.Y, 43ans, Béninoise, Commerçante à Parakou, 2022).

La planche ci-après présente des activités économiques exercées par les femmes la nuit grâce à leur accès à l'électricité.

Planche 1. Activités économiques exercées par des femmes la nuit à Agla à Cotonou

Soutenant ce point de vue, une autre femme renchérit en ces termes :

« *Mes heures de ventes supplémentaires dans la nuit m'aident à gagner beaucoup plus d'argent. C'est grâce à mes revenus que j'arrive à nourrir mes enfants, à payer leur scolarité à les soigner et assurer leur habillement. C'est avec ces revenus que j'ai pu construire cette maison et peux y habiter tranquillement avec mes enfants. Il faut avouer que le fait d'avoir de l'électricité de la SBEE en permanence dans notre quartier a permis à notre ménage de nous lancer dans le commerce, d'ouvrir une poissonnerie et de vendre des poulets surgelés. Les bénéfices que nous arrivons à dégager nous offre désormais la possibilité d'offrir au moins trois repas à nos enfants dans la journée*» (Propos de K.S, 40 ans, Béninoise, revendeuse à Agla, 2022).

Il en découle que l'énergie électrique a une influence positive sur la capacité des femmes à se faire des revenus et par ricochet sur leur autonomisation financière. Grâce à l'énergie électrique, les femmes sont en mesure de répondre à leurs différents besoins et à ceux de leurs familles.

« *C'est grâce à la disponibilité de l'électricité que j'ai pu mettre en valeur mes boutiques à des expatriés nigérians qui y font des recettes de 24h sur 24h sans interruption* » (Propos de M.F, 46 ans, Béninoise, Propriétaire d'un bien immobilier à Cotonou).

Par ailleurs, l'accès à l'électricité a une influence positive sur la capacité des ménages à satisfaire leurs besoins fondamentaux (sanitaire, alimentaire et éducatif). C'est ce que nous révèle ces propos d'une enquêté qui affirme :

« *Depuis que notre ménage a eu de l'électricité, le rendement scolaire des enfants s'est amélioré du fait qu'ils ne sont plus limités à la lumière du jour pour étudier. Il est fréquent de voir les enfants étudier jusqu'à tard dans la nuit* » (Propos de V.I, 39 ans, Béninoise, coiffeuse, Agla, 2022).

Toujours dans la même logique un autre enquêté vient confirmer ces propos en ajoutant :

« L'énergie électrique m'aide beaucoup dans mes activités génératrices de revenus et dans l'exercice de mes fonctions de mère. Grâce à l'argent que mes activités me génèrent je suis en mesure de répondre aux besoins essentiels de mes enfants. Quand ils sont malades je n'ai pas besoin d'attendre leur père. Contrairement à nous, ils ont la chance de faire leurs devoirs et de réviser leurs leçons à tout moment grâce à l'électricité que nous mettons à leur disposition » (Entretien réalisé ce 03/5/2022 à 09H53. Cité 2 fois

D'ailleurs, il ressort des entretiens que l'accès des femmes à l'électricité a renforcé leur pouvoir décisionnel au sein des ménages. C'est ce que nous révèle ces propos d'une enquêtée qui déclare :

« *Mon commerce m'a aidé à soutenir mon mari dans l'acquisition de notre compteur SBEE. Et depuis, ce dernier, qui ne me considérait pas, a changé de comportement envers moi. Il [mon mari] ne fait presque plus rien sans me consulter et de plus en plus, je participe financièrement aux dépenses du ménage et j'ai même le monopole de la gestion du courant. Avec l'électricité, j'ai réussi à développer mon commerce et j'avoue qu'avec les moyens que j'ai acquis, je ne suis plus dépendante financièrement d'un homme. Mon commerce à fleuri depuis que j'ai eu de l'électricité pour développer d'autres activités qui me permettent d'avoir d'argent pour me prendre moi-même en charge. Je vis d'ailleurs dans un foyer à ressources faibles et mais, mon apport dans les dépenses du ménage fait que j'ai le respect de mon mari et de toute sa famille y compris la mienne*. » Propos de D.N, 32 ans, Béninoise, commerçante à Parakou. Entretien réalisé ce 03/5/2022 à 13H 30.

En outre, les personnes démunies, ont toujours des problèmes de disponibilité d'électricité. Pour pallier les problèmes d'électricité auxquels ils sont confrontés, certains mettent en oeuvre des stratégies de résilience. Cette résilience consiste souvent à se doter de sources d'énergie telles que les mini kits solaires (lampe torche rechargeable au soleil communément appelé Yayi Boni.). C'est ce que nous illustre les propos de cette enquêté qui dit :

« *Mon ménage ne dispose pas d'un compteur de la SBEE. Mais cela ne nous a pas empêchés d'avoir la lumière grâce aux ''Yayi-Boni'' [mini kit solaire utilisé au Bénin depuis 2006 d'une valeur de 700 FCFA minimum] que j'utilise dans les chambres et dans la cour pour l'éclairage.* » (Propos de B.G, 57 ans, Béninois, chef de ménage, Parakou, 2022).

Ce kit solaire accessible à tous du fait de son prix abordable à leur portée et de sa recharge naturelle qui n'est pas payante est acheté suivant la bourse financière de chacun. C'est ce que nous dit cet enquêté lorsqu'il déclare :

« J*'utilise les kits solaires d'une valeur de 7000F, dotés d'ampoules et de ports USB permettant de charger les portables. Le kit n'étant pas cher, il me permet, à moi et ma famille, de ne plus parcourir de longues distances pour recharger nos portables.* » (Propos de F.N, 44 ans, mécanicien, Chef de ménage à Parakou, 2022).

XIV. De l'analyse de ces données de terrain, il apparait que l'efficacité énergique est cruciale pour le développement des activités économiques des femmes et par conséquent de leur autonomisation économique.Discussion

A. *Le développement des AGR à l'épreuve des inégalités d'accès des femmes à l'électricité*

L'énergie électrique est une ressource qui se présente aujourd'hui comme étant le moteur du développement. L'électricité est une forme d'énergie nécessaire aux usages domestiques, industriels et techniques. On note que l'ensemble des systèmes sanitaires, éducatifs, d'adduction en eau potable, de transport sont très dépendants de l'énergie mais surtout de l'électricité [04]. Son implication dans la création d'AGR fait d'elle un facteur déterminant de répression de la pauvreté et du chômage. Les femmes sont aujourd'hui très impliquées dans l'exercice des AGR et elles y démontrent un très grand intérêt. Cela peut s'expliquer par le fait qu'elles soient les plus affectées par la pauvreté. C'est d'ailleurs à titre illustratif que S. Vallée [8] affirme que, encore aujourd'hui, la pauvreté frappe plus durement les femmes que les hommes, autant dans les pays du Nord que du Sud, notamment en raison des inégalités sociales et du manque d'opportunités qui les confinent à la pauvreté. Cependant, les données de terrain démontrent que les femmes sont confrontées à des difficultés d'accès à l'électricité et qu'elles sont les plus touchées par la pauvreté électrique. Au Bénin à l'instar de l'Afrique subsaharienne, le secteur de l'énergie souffre d'un grave manque d'investissement et les groupes vulnérables, en particulier les femmes et les réfugiés, sont touchés de manière disproportionnée [6]. Dans une société où l'organisation sociale de type patriarcal confère à l'homme le monopole de gestion électrique, la femme se voit limitée dans ses efforts de progrès. Les responsabilités restent strictement réparties au sein des foyers. Elles prennent appui sur des institutions coutumières (système lignager de la répartition des tâches, du mariage, de la résidence, de l'héritage, du foncier), établissant une hiérarchie des rôles qui conforte la place prééminente des hommes dans la sphère de la production et celles des femmes plutôt dans celles de la reproduction [5].

Ainsi, plusieurs facteurs d'ordre économique (faible pouvoir d'achat des femmes, pauvreté), social (les construits sociaux, les institutions sociales), ou encore anthropologique (mythes, stéréotypes, normes et valeurs) peuvent être à l'origine du statut social assignée à la femme la rendant moins éligible à l'accès à l'énergie électrique comparativement à l'homme. Pour les diverses observations qui s'en suivent, des dispositions s'imposent pour garantir l'accès équitable à l'énergie aux femmes.

De ce qui précède, on note un accès inégal aux moyens de productions et en occurrence à l'énergie électrique. Ce qui renforce les disparités de genre et féminise la pauvreté énergétique.

B. *Féminisation de la pauvreté énergétique, un obstacle majeur à l'autonomisation économique des femmes*

Les données de terrain révèlent une pauvreté énergétique accentuée chez les femmes (69%) contre 31% chez les hommes. Selon l'Institut National de la Statistique et de l'Analyse Economique du Bénin (INSAE, 2015), les inégalités d'accès à l'énergie ont été accentuées au niveau des femmes entre 2011 et 2015. Pour les ménages dirigés par les femmes, l'indice d'inégalité est passé de 0,441 en 2011 à

0,454 en 2015, soit une hausse de 0,013 point contre 0,003pour les ménages dirigés par les hommes [3]. Par conséquent, les femmes ont moins accès aux intrants (alimentation énergétique) pour la promotion de leurs activités génératrices de revenus. A l'instar des données de terrain, le rapport indique que la plupart des femmes sont pour la plupart dépendantes des hommes, ce qui constitue une forme de discrimination associée à leur statut matrimonial ou aux stéréotypes développés par la société. Une autre discrimination porte sur l'accès aux crédits. N'ayant pas d'actif en propre à offrir en garanti aux institutions de microfinance, les femmes rencontrent souvent des difficultés d'accès aux services financiers. Pourtant, la connexion aux réseaux électriques a un coût considérable qui n'est pas à la portée de toutes les femmes compte tenu de leurs niveaux de vie et de leurs revenus. Près de 90% des femmes interrogées ont exprimé un désir manifeste de disposer de l'énergie électrique tout en ayant le monopole de gestion et de contrôle de consommation. Or cette aspiration reste compromise du fait des difficultés d'accès aux services financiers décentralisés dont les procédures administratives restent généralement en défaveur des femmes à cause des garanties exigées s.

Face au fonctionnement actuel de la société, lil se dégage une disparité d'accès et de contrôle à l'électricité entre les hommes et les femmes qui tire son origine dans la situation de d précarité économique à laquelle sont exposées les femmes. Le phénomène de la féminisation de la pauvreté s'explique ainsi principalement par des stéréotypes de genre véhiculés par la société mais aussi par des facteurs économiques. Les héritages de la domination masculine et la socialisation primaire cloisonnent les femmes dans leur rôle familial et restreignent leur épanouissement professionnel. Discrimination sur le marché de l'emploi, répartition inégalitaire du travail domestique non rémunéré ou encore conciliation complexe des fonctions familiale et professionnelle favorisent dès lors la position sociale précaire des femmes et aggrave leur situation de pauvreté [7].

Par conséquent, le développement des activités entrepreneuriales des femmes est fortement influencé par leur capacité à disposer d'une énergie fiable et de qualité reste influencée .

XV. Conclusion

Le développement des activités génératrices de revenus des femmes à Parakou et à Cotonou est aujourd'hui dépendant en grande partie de l'énergie électrique. Les données de terrains révèlent que 67 % des femmes ont recours à l'énergie conventionnelle pour leurs différentes activités. Cette proportion est de 20 % pour l'énergie solaire contre 12 % pour les groupes électrogènes. L'énergie électrique rend les femmes beaucoup plus autonomes dans la poursuite de leurs AGR. L'accès et le contrôle de de l'énergie électrique permet aux femmes entrepreneures d'AGR de faire de meilleures recettes dans leurs entreprises et de contribuer au bien-être de leurs ménages. Cependant, il apparaît que les femmes sont confrontées à des difficultés d'accès et de gestion de l'énergie électrique. Contrairement aux hommes qui en sont les garants dans la 69% des ménages, les femmes pour des raisons d'ordre économique, social ou encore anthropologique restent limitées dans leurs rapports à l'énergie électrique ce qui constitue un obstacle dans l'exercice de leurs AGR.

De plus, la durabilité de leurs AGR dépend en grande partie de cette ressource. Dès lors, il importe de se demander s'il n'est pas opportun d'opter pour des énergies propres telles que l'énergie solaire d'une part, et d'autre part de tendre vers la subvention de cette ressource pour rendre durablement les femmes autonomes dans le déroulement de leurs AGR ?

Ce choix renforcerait inévitablement leur autonomisation économique et le bien-être des ménages et par richochet le développement inclusif durable des communautés étudiées.

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Hybrid energy system: an alternative for electrifying the suburbs of Lubumbashi in DR Congo

Bonaventure Banza wa Banza
School of Industrial Engineering
University of Lubumbashi
Lubumbashi, DR Congo
banzaviola2007@yahoor.fr

Philippe Bouillard
BATir Service (Building, Architecture and Town Planning)
Université Libre de Bruxelles
Brussels, Belgium

Kiseya Flory Tshikala
School of Industrial Engineering
University of Lubumbashi
Lubumbashi, DR Congo

Diambomba Hyacinthe Tungadio
Electrical and electronic Engineering Science
University of Johannesburg
South Africa

***Abstract*—The aim of this study was to assess alternative sources of electricity and to evaluate the implementation of a hybrid energy system as a solution to electrify the suburbs of Lubumbashi. Socio-economic survey data from 5,270 households revealed 163 mini-grids using diesel generators and serving 1143 households. Simulation, optimization and sensitivity analysis with the HOMER revealed that the optimal solution is obtained when the load is fed by a hybrid system photovoltaic-diesel system with storage on 96 batteries of 1 kWh. Photovoltaic-diesel reduces emissions by more than 34% compared to diesel system alone. This study recommends replacing diesel mini-grids with Photovoltaic-diesel hybrid mini-grids as an effective measure to reduce diesel fuel consumption and greenhouse gas emissions, while providing 24-hour electrical service in non-electrified suburbs.**

Keywords*— *Photovoltaic, HOMER, mini-grid, socio-economic status, Lubumbashi

XVI. Introduction

In DR Congo, the national electrification rate is currently 9%, and only 1% if only the rural world (76.8% of the Congolese population) is taken into account. In Lubumbashi, the second largest city in DR Congo, [1] reported an electricity access rate of 61.6% at the urban scale characterized by frequent and unpredictable power cuts.

In Lubumbashi, as in most developing cities, the electrification of low-density peripheral neighborhoods represents a significant investment [2]. Low building density is usually accompanied by a relatively high cost of connection to the electricity grid [2]. These low-density neighborhoods where live most of low-income populations, raise issues of profitability and sustainability of electrification projects. The weak capacity of the SNEL (National Electricity Company) to extend the power grids and the uncontrolled urbanization under which most of these neighborhoods are established require urgent recourse to appropriate policies. For low-income households in particular, extending the electricity grid is not an option [3]. In addition, the criteria used to select the neighborhoods to be electrified (for example, the distance from the electricity grid, the size of the population, the ability of households to pay connection fees and the costs of services) only favor central districts and high-income households [4].

Recently, [1] showed that due to the lack of electricity or poor-quality services, most households of Lubumbashi use oversized alternative energy sources. Indeed, the majority of households in informal neighborhoods make more use of collective solutions such as the generator and individual such as solar panels as an alternative source of electricity. However, each of these two technologies has limitations. The current challenge is to propose accessible and efficient solutions. The studies of Alkon [5] and Alam & Bhattacharyya in [6] highlight the willingness to pay for modern energy, while Khandker et al. [7] show a strong relationship between income and energy poverty. Other studies, on the other hand, only explain rural electrification and access to energy [8-9]. The role of socio-economic factors in access to mini-grids fueled by diesel groups has so far been less elucidated.

Based on the literature, no study has so far been conducted in Lubumbashi to evaluate the feasibility of a hybrid photovoltaic (PV)-generator mini-grid. Another novelty of this study is that, to our knowledge, most of the feasibility studies for PV-diesel mini-grid in most developing countries have focused on rural areas [10-11]. Moreover, these studied focused on the techno-economic feasibility. The current research answers the following question: Is the use of hybrid PV-diesel system a technically, environmentally, and economically feasible solution for non-electrified households of Lubumbashi?

XVII. METHODOLOGY

A. *Study site*

This study was conducted in Lubumbashi (south-easter The Democratic Republic of Congo, at 11 ° 40 'S and 27 ° 29' East). Administratively, the city is composed of 43 neighborhoods grouped in 7 municipalities [12] including: Lubumbashi, Kenya, Kampemba, Katuba, Kamalondo, Ruashi and Annexe. Lubumbashi is confronted with several difficulties: the existence of under-equipped and unstructured peripheral districts, a confusion in the roles and responsibilities of the actors concerning town planning and urban management, an excessive spreading of the city by the creation of subdivisions without a master plan, coherence, access roads and equipment reserves [13]. The Luwowoshi district located in the north-east of Lubumbashi city has been selected as a pilot district to evaluate the technical-economic and environmental feasibility of a hybrid PV-diesel mini-grid. This district has a population of about 70,000 inhabitants, or 3.5% of the population of Lubumbashi and covers an area of 38.9 km2.

B. Data collection

Solar radiation data of Lubumbashi were obtained from the National Aeronautics and Space Administration (NASA) website. These data were used during the simulation under HOMER (Hybrid Optimization Model for Energy Renewable), because the power of the solar panels that this computation software depends on the incident average illumination [14].

The socio-economic data come from our large database of surveys covering 5,270 households throughout the city of Lubumbashi [1]. A total of 163 mini-grids fueled by diesel generators serving 1143 households, or 21.6% of households surveyed, were identified. For each household connected to the diesel mini-grid, the following socio-economic variables were selected: source of income, average monthly income and level of education.

Data used for simulation in HOMER were collected in the Luwowoshi district where loads from consumers at the one-hour interval during a day were collected over a period of one month using the method proposed by [15-17]. Obtained load profile had a typical shape of a residential area as defined by Lambert [14], characterized by a peak in the evening [18].

C. Simulation, optimization and sensitivity analysis

Three operating scenarios (Figure 1) of the hybrid mini-grid were tested. Three crucial steps were followed: simulation, optimization and sensitivity analysis. During the simulation, it was discussed to verify the technical feasibility of the mini-grid then the optimization made it possible to determine which configuration presents the lowest costs. And lastly, the sensitivity analysis made it possible to determine the impact of certain inputs on the cost of energy.

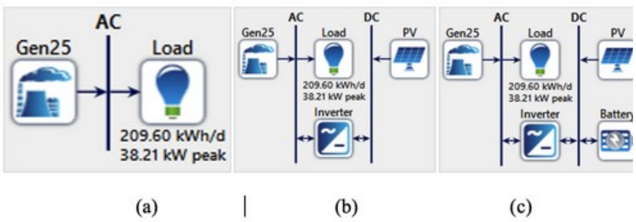

Figure 1. System configuration (a) diesel only group; (b) diesel - PV; (c) diesel-PV group with batteries (Source: Authors from HOMER)

PV-systems*:* PV systems are modeled under HOMER as DC generators when exposed to solar radiation and their output power can be deduced from the following relationship [14, 19-24]:

$$P_{PV}=Y_{PV}f_{PV}\left(\frac{G_T}{G_{T,STC}}\right)\left[1+\alpha_p\left(T_C-T_{C,STC}\right)\right]$$

(1)

With, Y_{PV} is the rated power under standard test conditions, f_{PV} is the depreciation factor of solar panels, GT is incident illuminance, G_T, S_{TC} is illumination under standard test conditions, αp is the coefficient panel temperature (% / ° C), TC is the temperature of the PV cell in ° C, TC, STC is the temperature of the PV cell at standard conditions (25°C). In a PV-diesel hybrid mini-grid, the energy cost is greater than the cost of the conventional grid because of the high cost of storage systems and the cost of diesel [25]. To reduce this cost, we propose as part of this study that the peak loads are ensured by the diesel group there is thus limited time of use of the diesel group and reduction in fuel consumption. The PV system powers the daytime load and charges the batteries, which in turn enable frequency regulation [26-27]. The night charges are powered by the battery system. In the event of a power failure at any time during these periods for any reason, the generator must start automatically. The design criteria for the PV system were based on a demand for 11 kW off-peak power between morning and evening. Thus, the PV system must meet the loads of the day. It consists of 40 polycrystalline PV modules of 275 Wc each, a nominal voltage of 31.2 V DC and a nominal current of 8.82 A connected in parallel.

Batteries: The battery system must only respond to night-time charges, which are 4 kW between 23h and 4h, mean an energy of 20 kWh, considering an average of 3, the number of days of autonomy, for a maximum discharge of 80% and η_{out} the total efficiency is given by the battery yield (0.85) multiplied by the efficiency of the inverter (0.9) which is 0.765. Using Equation 2 [28-29].

$$Bsc=\frac{Nc\,.\,Ej}{Dd\,.\,\eta out}$$

(3)

Where Nc: number of days of autonomy; Ej: daily energy; Dd: maximum discharge; Bsc: storage capacity.

The storage capacity becomes approximately 98039 Wh. Since the selected DC bus voltage is 24 V, then the required amp hours of batteries will be 4085 Ah. Considering a battery of 6 V and 167 Ah. In this case there will be 24 strings connected in parallel and each string consisting of four batteries connected in series to have the 24 V DC bus, a total of 96 batteries.

Inverter: To ensure the reliability and availability of the power system, two inverters have been selected for an input voltage of 24 V and a 220 VAC output. The choice of the inverter is based on its ability to manage the expected maximum power of the loads used in alternating current. Therefore, it can be selected as 20% higher than the nominal power of the total charges presented. Thus, the rated power per inverter becomes 15 kW. The specifications of the inverter will be 15 kW, 24V DC, 220V AC and 50Hz. The inverters are connected to 2 separate 220 V AC bus bars so that during the day, each feeds separate loads. At night, an inverter can be isolated for routine maintenance, for example.

Economic evaluation: Economically, HOMER evaluates a project according to two criteria, the first is the current net cost, Net Present Cost in English (NPC) which is the present value of all costs that will occur during the lifetime of the project. This cost includes equipment purchase costs, replacement costs, maintenance costs, fuel costs and environmental penalties [14].

Environmental assessment: Using HOMER, an environmental scan was conducted based on fuel consumption and greenhouse gas emissions. For this evaluation, three scenarios including diesel alone, PV-Diesel and PV-Diesel with energy storage system were studied.

XVIII. RESULTS

A. Spatial distribution of alternative sources of electricity in the city of Lubumbashi

The spatial distribution of diesel mini-grid, individual electric generators (generator), solar panels in the city of Lubumbashi is given in Figure 2. The mini-grids are more concentrated in the suburbs. The highest density of mini-grids is observed in Kisale, Kalebuka and Kafubu districts. The electric generator as an individual source of access to electricity is more common in Ruashi commune, Gambela and Lufira district. The use of solar panels is more common in the Mampala and Gambela districts. Overall, the density of all sources of electricity studied increases as it moves away from the Lubumbashi urban core to the denser zone of spontaneous peripheral neighborhoods. However, the density of these electricity sources is decreasing considerably in neighborhoods that are increasingly distant from the city center.

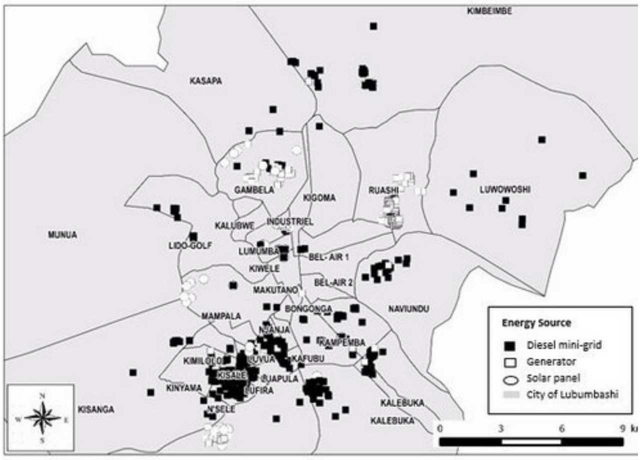

Figure 2. Spatial distribution of alternative sources of electricity in different districts of Lubumbashi (Source: authors' survey).

B. Technico-economic analysis of the proposed hybrid PV-diesel system

Figure 3 shows the results of the economic evaluation of a mini-grid in the Luwowoshi district. The simulation of the system when we are in a scenario in which the entire load is powered only by a generator, indicates that the COE (Cost of Energy) is USD 0.451 which is the cost of energy at kWh, the NPC (Net Preset Cost) is USD 445,681 and the group consumes about 29,779 liters per year. These results are found for an average daily energy consumption of 262 kWh. And for the liter of fuel going back to USD 1.1. In a scenario where the load is powered by a generator and a PV system, the energy cost is USD 0.470 per kWh, the NPC is USD 464.507. The fuel consumption is 27108 liters per year. As for the first scenario, these results are for an average daily consumption of 262 kWh. In the last scenario, the load is powered by a diesel-PV system with storage on 96 batteries of 1kWh, this configuration offers us the lowest cost of energy compared to the other two configurations is USD 0.385 / kWh. It gives an NPC of USD 381,097 and an annual diesel consumption of 19518 liters.

PV (kW)	Gen25 (kW)	Bat	Inverter (kW)	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
11.0			30.0	$0.231	$55,251	$1,798	$32,003	100
11.0		96	30.0	$0.440	$106,380	$3,526	$60,803	100
11.0	25.0	96	30.0	$0.385	$381,097	$23,616	$75,803	16.9
	25.0			$0.451	$445,681	$33,315	$15,000	0
	25.0	96	30.0	$0.459	$454,126	$30,348	$61,800	0
11.0	25.0		30.0	$0.470	$464,507	$32,296	$47,003	4.81

Figure 3. Simulation results with HOMER

Figure 4 shows a distribution of the cost of energy according to the demand and the price of fuel. We can understand from this figure that the cost of energy would be the lowest if we had a strong demand and a price of the smaller diesel.

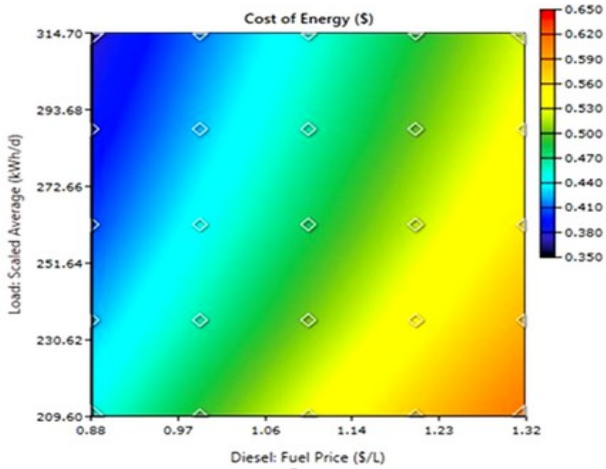

Figure 4. Change in COE based on diesel price and HOMER charge.

By varying the two sensitivities parameters, namely the fuel price and the fuel load, by a maximum of 20%, we evaluate the effect they have on the cost of energy in the three scenarios studied. Figures 5 show that an increase in the price of fuel causes an increase in the cost of energy while an increase in the load reduces the cost of energy.

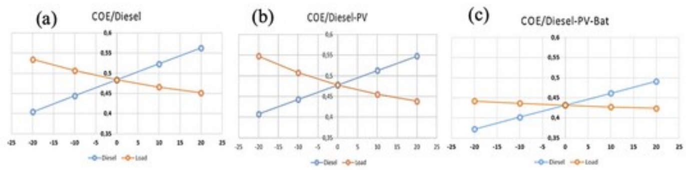

Figure 5. Change in COE based on diesel price and load for Diesel (a), Diesel-PV (b) and Diesel-PV-Battery configurations.

XIX. C. Environmental Analysis

Total fuel consumption per day per hour is higher when using diesel alone compared to using diesel in combination with photovoltaics. The addition of batteries to PV-Diesel reduces fuel consumption by more than 34% (Table 1).

Table 1. Fuel consumption according to different scenarios

Quantity	Fuel Consumption (L)		
	Diesel	PV-Diesel	PV-Diesel-Batteries
Total consumption	29779	27108	19518
Daily average consumption	81,6	74,3	53,5
Hourly average consumption	3,4	3,09	2,23

Table 2 shows that CO_2 is by far the greenhouse gas most emitted by the use of diesel. Whatever the greenhouse gas considered, its emission is higher if the diesel is used alone and decreases with the adoption of hybrid solutions. The use of PV-Diesel-Batteries reduces emissions by more than 34%.

Table 2. Quantity of Greenhouse Gases Emitted for Different Scenarios

Types de gas	Emission of greenhouse gases (kg/an)		
	Diesel	PV-Diesel	PV-Diesel-Batteries
Carbon dioxide (CO_2)	77959	70966	51095
Carbon monoxide (CO)	487	443	319
Unburned hydrocarbons (HC)	21,4	19,5	14,1
Volatile particle (PVo)	2,92	2,66	1,91
Sulphur dioxide (SO_2)	191	174	125
Nitrogen oxides (NOx)	457	416	300

Figure 6 presents a sensitivity analysis of greenhouse gas emissions and fuel consumption with increasing power of batteries and PV modules. Overall emissions of all greenhouse gases and fuel consumption drop significantly with the increase in the power of batteries and PV modules. It is also noted in this figure that the emissions decrease little when one puts PV, without storage and when one puts storage for low values of PV, in both cases the diesel group continues to function to cover the rest of the load, which increases emissions.

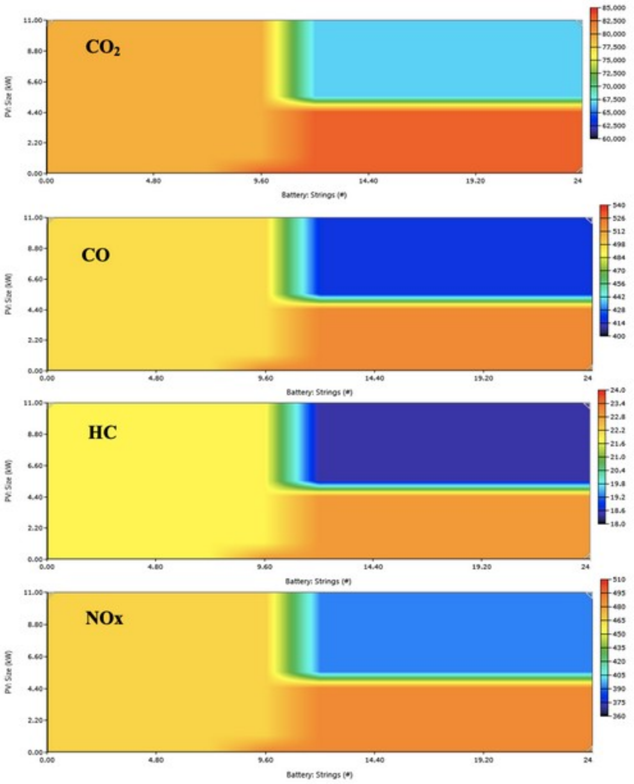

Figure 6. Variation of greenhouse gas emissions by battery power and PV modules calculated with HOMER

XX. DISCUSSION

This study showed that diesel mini-grid are concentrated in outlying neighborhoods (62.8%) and to a lesser extent in some central neighborhoods (37.2%). This observation is mainly due either to the absence of the electricity grid in the outlying districts or poor-quality electricity characterized by frequent cut off (up to 14 hours / days) [1]. Banza et al. [2] revealed that between 1996 and 2014, the distribution of electric cabins did not follow urban sprawl. The electric generator as an individual source of access to electricity is more common in Ruashi municipality, Gambela district and Lufira districts. However, this is a more expensive solution than the direct connection to the electricity grid [30-31]. The cost of electricity produced by electric generators in Sub-Saharan Africa is estimated between 0.35 and USD 0.40/ kWh [32], this is four to five times higher than the price of kWh sold by SNEL.

The use of solar panels is more common in Mampala and Gambela districts. Overall, the density of all alternative sources of electricity studied increases as it moves away from the urban core [33-34] from Lubumbashi to the zone of higher density consisting of spontaneous peripheral neighborhoods. The high density of diesel mini-grids and solar panels in the peripheral neighborhood belt is motivated by the inaction of the public authorities in providing the service [2]. On the other hand, in the neighborhoods that are more distant from the city center, the collective sources of access to electricity such as the diesel mini-grid are limited by low density of the building. This situation offers the unique possibility of using individual solutions such as photovoltaics (PV) and the individual electrical generator [32].

Monthly income and farm income source are negatively correlated to mini-diesel subscriptions (Data not shown). On the other hand, the other (diversified) source of income is positively correlated to the diesel mini-grid subscription. This study corroborates Muhoza and Johnson's [33] claim that to improve the payment capacity of users of mini-grids, it is necessary to diversify their sources of income. With respect to the monthly income variable, the finding in this study shows that higher-income households do not use collective solutions such as mini-diesel. Typically, these households live in serviced central neighborhoods using the personal diesel generator and / or the PV system as an alternative source of electricity in the event of a power outage [34]. Other high-income households show the least satisfaction with the use of fossil fuel for the PV system, this has also been shown in Bangladesh by Alam and Bhattacharyya [35]. The number of household managers with a "secondary" level of education increases significantly with the number of subscribers to the diesel mini-grid.

The level of education plays an important role in the selection and consumption of various types of fuels [36]. It has an impact on the willingness to pay for the energy consumed when the household is connected to the mini-grid [37]. Highly educated households are less connected to the diesel mini-grid (Data not shown). This may be justified by the fact that people with a higher level of education generally adopt the autonomic PV system than those with a lower level of education [34, 38-40].

This study also showed that the high numbers of households subscribing to the diesel mini-grid are particularly installed in Katuba commune. Their sources of revenue are mainly small businesses and other activities. In addition, the secondary level of education characterizes the households connected to the mini-grid in Katuba commune. The level of education and the income next to the location of the household, are the factors that determine the most access of a household to the diesel mini-grid.

According to our previous work [1], a large proportion of households in Lubumbashi (29.2%) use generators to meet their electrical energy needs. Only 3% of households surveyed use the photovoltaic system. The hybrid system as studied in this work presents an alternative solution to the high cost represented by an extension of the conventional electricity grid for the outlying districts of Lubumbashi. The important indicator of the durability of this type of mini-grid is the cost of energy. Evaluating a particular energy system for its techno-economic feasibility is of utmost importance if the system is to function satisfactorily at a given location [41].

The optimal solution found in this study involves an energy cost of USD 0.385 / kWh. This value is close to those found by Batha [42] and Lao [43] for similar applications respectively in Ethiopia and Cambodia, and lower than the cost found by Abanda et al. [44] in Cameroon. The cost found in this study is much higher than the price of electricity sold by SNEL (USD 0.087 / kWh). The high unit cost of electricity found in this study could be associated with the high cost of photovoltaic solar modules [11]. From an economic point of view, the hybrid PV system is therefore less competitive than the electricity supplied to homes by the conventional grid.

The lower competitiveness of photovoltaic solar systems, regardless of the country's solar potential, could be explained by the fact that government policies to increase the amount of electricity produced have been largely concentrated on hydroelectric power stations [44]. In the outlying districts, where the extension of the electricity grid is less likely due to the shortage of electricity in the city, the current cost of energy, as found in this study remains affordable and reliable especially in the long term. The African Development Bank [45] has shown that for electricity from their diesel mini-grid SNEL would apply tariffs ranging from USD 0.32 / kWh to USD 0.40 / kWh [46].

According to Halabi et al. [47], the hybrid PV-diesel-battery system has the best technical characteristics and very good economic characteristics based on the overall cost of the system. According to our study, the cost of energy is high by using PV alone compared to using the diesel engine alone. The environmental analysis showed that regardless of the greenhouse gas considered, its emission is higher if the diesel is used alone and decreases with the adoption of hybrid solutions. The use of PV-diesel-batteries reduces emissions by more than 34%.

XXI. CONCLUSION

The objective of this research was to assess alternative sources of electricity and to evaluate the implementation of a hybrid energy system as a solution to electrify the suburbs of Lubumbashi. This study showed an increase in the density of solar panels, electric generators and diesel mini-grids with distance from downtown Lubumbashi. The level of education and the income next to the location of the household, are the factors that determine the most access of a household to the diesel mini-grid.

We found that the hybrid PV-diesel-battery system presents an alternative solution to the high cost represented by an extension of the conventional electricity grid for the outlying districts of Lubumbashi. This technology is environment friendly as compared to using diesel generator alone as reduces emissions by more than 34%. The use of a hybrid PV-diesel battery system can significantly reduce dependence on available diesel resources only if the design of the diesel generator and PV array is correctly implemented.

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Etat des lieux de la réglementation de l'utilisation des rayonnements ionisants au Bénin en 2021

Kuassi Marcellin Amoussou-Guenou
Autorité nationale de sûreté radiologique et de radioprotection Présidence de la République du Bénin
Cotonou, Benin
agkuassimarcellin@yahoo.fr

Mahougnon Boniface Zinsou
Autorité nationale de sûreté radiologique et de radioprotection Présidence de la République du Bénin
Cotonou, Benin
mahougnonbonifacezinsou@yahoo.fr

Alfred Arnaud Gbetchedji
Autorité nationale de sûreté radiologique et de radioprotection
Présidence de la République du Bénin
Cotonou, Benin
galfredarnaud@yahoo.fr

Stanislas Jean-Pierre Sehounhouedo
Autorité nationale de sûreté radiologique et de radioprotection
Présidence de la République du Bénin
Cotonou, Benin
ssehouendo@yahoo.com

Lydie Gaelle Famaga
Autorité nationale de sûreté radiologique et de radioprotection Présidence de la République du Bénin
Cotonou, Benin
famagagaelle@yahoo.fr

***Abstract*—Ce manuscrit présente les avancées de l'Autorité nationale de Sûreté radiologique et de Radioprotection (ANSR) en 2021 dans le cadre de l'utilisation sûre et sécurisée de l'atome à des fins de développement. Après un rappel des prérogatives et obligations de l'ANSR, les auteurs présentent la méthodologie ayant gouverné leurs actions et les résultats auxquels ils ont abouti. Ces résultats consistent en sept décisions d'application de la loi nucléaire approuvées et consultables sur le site ansr.gouv.bj, la mise à jour du RASIMS, 223 installations et activités recensées dont 48,88%, 43,50% et 7,62% respectivement dans les secteurs médical, industriel et de la recherche, la formation de la Personne Compétente en Radioprotection (PCR) de chaque installation sur les procédures de déclaration à l'ANSR, 17 déclarations à l'AIEA en 2021 en vertu du Protocole additionnel des accords de garanties nucléaires. Cent quinze (115) installations ont été enregistrées au cours de la première année d'intervention de l'ANSR. Parmi ces installations, 55 (47,83 %) ont nommé leur PCR, 54 ont été déclarées et un certificat de déclaration a été délivré à 32 d'entre elles (57,41 %). Sept (07) sources radioactives dont 0, 2, 1, 2 et 2 respectivement de catégories 1, 2, 3, 4 et 5 ont été répertoriées de même que 74 générateurs de RX de tension maximale comprise entre 35kV à 150kV. Malgré ces progrès de l'ANSR, beaucoup de défis restent à relever.**

***Keywords*— ANSR, énergie atomique, sûreté radiologique, sécurité nucléaire**

XXII. Introduction

L'utilité des sources de rayonnements ionisants dans tous les secteurs de la vie n'est plus à démontrer. Toutefois, ces sources peuvent causer des effets nocifs pour l'environnement et la santé, surtout lorsqu'elles sont utilisées imprudemment. Ces effets connus sous le nom d'effets déterministes et d'effets stochastiques sont variés. Il peut s'agir d'une stérilité transitoire ou définitive, décès, ou à long terme de cancer radio-induit ou effets génétiques sur la descendance.

Pour contribuer à un meilleur encadrement de l'utilisation des rayonnements ionisants aux fins d'en limiter les risques et effets indésirables, l'Organisation Mondiale de la Santé (OMS) a coopéré avec l'Agence Internationale de l'Energie Atomique (AIEA) et cinq autres organisations internationales pour réviser les normes fondamentales internationales relatives à la sûreté radiologique et la sécurité nucléaire. Ces normes obligent les Etats membres à mettre en place un cadre réglementaire fonctionnel visant à contrôler l'utilisation des sources de rayonnements ionisants à des fins pacifiques.

Ce travail présente l'état des lieux de la réglementation des rayonnements ionisants au Bénin ainsi que les avancées majeures de l'ANSR au cours de sa première année de fonctionnement.

XXIII. Cadre, materiels et methode

A. Cadre

Le présent manuscrit est élaboré par l'Autorité nationale de Sûreté radiologique et de Radioprotection (ANSR). Il s'agit d'une institution sous la tutelle de la présidence de la République, créée par la loi n°2017-29 portant sûreté radiologique et sécurité nucléaire en République du Bénin [1], une prescription de l'Agence Internationale de l'Energie Atomique (AIEA) consécutive à l'adhésion de la République du Bénin à cette Organisation en 1999.

Les prérogatives de l'ANSR sont entre autres, de délivrer des autorisations aux installations associées à l'utilisation des rayonnements ionisants et d'inspecter ces installations [1].

Les obligations de l'ANSR consistent à, d'une part au plan national, élaborer et suivre la réglementation de l'utilisation des rayonnements ionisants, établir et de mettre à jour le registre national des sources, et d'autre part au plan international, fournir à l'AIEA toutes les informations sur les matières nucléaires, en vertu des accords de garantie [1,2].

B. L'ANSR a conçu et développé le site internet consultable par le lien ansr.gouv.bj.

Sur ce site, accessible à tous les exploitants des installations et activités, les différents outils utilisés dans le cadre de ce travail sont consultables. Il s'agit entre autres de dix-sept (17) formulaires de déclaration, demande d'autorisation, des fiches d'identification des générateurs, etc.

C. Méthode

Au plan national, les textes d'application de la loi nucléaire ont été élaborés puis approuvés par l'instance compétente. Par la suite, du 26 juillet au 05 octobre 2021, l'ANSR a effectué une tournée nationale dans les 12 départements du Bénin, à la faveur de deux-cent vingt-trois (223) invitations adressées par les préfets des départements aux exploitants des installations utilisatrices de rayonnements ionisants dans les secteurs médical, industriel et de recherche, ainsi qu'aux Personnes Compétentes en Radioprotection (PCR) de ces installations.

Au cours des séances de sensibilisation, les exploitants et les PCR de leurs installations ont été invités à remplir les outils pertinents disponibles sur le site de l'ANSR et à les soumettre pour étude à l'Autorité.

Les dossiers réceptionnés à l'ANSR ont été enregistrés, dépouillés puis évalués par les services compétents.

Un certificat de déclaration ou une licence d'autorisation a été délivré aux responsables des installations lorsque les exigences sont satisfaites.

Au plan international, sur la base des informations disponibles, l'ANSR a procédé à des déclarations périodiques des matières nucléaires sur la plateforme dédiée de l'AIEA et a mis à jour la plateforme du Système d'Information des Autorités Réglementaires (RASIMS).

XXIV. Résultats

Les résultats sont circonscrits au cadre réglementaire, aux données sur les installations et aux actions réglementaires étant donné l'absence de services opérationnels de suivi dosimétrique des travailleurs et de contrôle qualité des appareils émetteurs de rayonnements ionisants.

A. Le cadre réglementaire de l'utilisation des rayonnements ionisants

En 2021, sept Décisions d'application de la loi nucléaire ont été adoptées. Ces textes sont listés dans tableau ci-après :

TABLE V. Liste des Décisions d'application de la loi nucléaire adoptées au Bénin en 2021

N°	Intitulé	Référence
1	Décision N°069-2021/PR/P-CS/SP-ANSR/SA du 25 mars 2021 portant régime de déclarations des installations et activités utilisatrices de rayonnements ionisants en République du Bénin	[3]
2	Décision N°070-2021/PR/P-CS/SP-ANSR/SA du 25 mars 2021 portant régime des Autorisations délivrées par l'Autorité Nationale de Sûreté Radiologique et de Radioprotection	[4]
3	Décision N°071-2021/PR/P-CS/SP-ANSR/SA du 25 mars 2021 portant régime des Inspections effectuées par l'Autorité Nationale de Sûreté Radiologique et de Radioprotection	[5]
4	Décision N°072-2021/PR/P-CS/SP-ANSR/SA du 25 mars 2021 portant Radioprotection en situation d'exposition médicale en République du Bénin	[6]
5	Décision N°073-2021/PR/P-CS/SP-ANSR/SA du 25 mars 2021 portant radioprotection des travailleurs dans les installations et activités utilisatrices des rayonnements ionisants	[7]
6	Décision N°117-2021/PR/P-CS/SP-ANSR/SA du 06 mai 2021 portant responsabilités et obligations des Titulaires d'autorisations des installations et activités dans le domaine des rayonnements ionisants en République du Bénin	[8]
7	Décision N°118-2021/PR/P-CS/SP-ANSR/SA du 06 mai 2021 portant sûreté et sécurité des transports de matières radioactives en République du Bénin	[9]

Ces textes réglementaires s'alignent également d'une part sur les instruments juridiques internationaux ratifiés par le Bénin, à savoir : le Traité de Non-Prolifération [10], des Accords de Garanties [11], la Convention sur la Protection Physique des Matières Nucléaires (CPPNM) et son Amendement [12], la Convention de Vienne relative à la responsabilité civile en matière de dommages nucléaires [13], le protocole commun relatif à l'application de la Convention de Vienne et de la Convention de Paris [14], le protocole portant amendement à la Convention de Vienne relative à la responsabilité civile en matière de dommages nucléaires [15], la Convention sur la réparation complémentaire des dommages nucléaires [16], la Convention sur la notification rapide d'un accident nucléaire [17], la Convention sur l'assistance en cas d'accident nucléaire ou de situation d'urgence radiologique [18], la Convention sur la sûreté nucléaire [19], la Convention commune sur la sûreté de la gestion du combustible usé et sur la sûreté de la gestion des déchets radioactifs [20], d'autre part sur le code du travail [21], la loi nucléaire [1], le code pénal [22], le décret portant approbation des statuts de l'ANSR [2] et des arrêtés ministériels [23,24,25].

B. Les données sur les installations et activités associées aux rayonnements ionisants

Après évaluation des structures recensées, 115 d'entre elles ont été enregistrées sur la liste des installations et activités impliquées directement dans l'utilisation des rayonnements ionisants à la date du 15 octobre 2021. Parmi ces installations 55 (47,83%) ont nommé une Personne Compétente en Radioprotection (PCR) conformément aux textes en vigueur.

Le tableau II présente la répartition des installations et activités par départements et secteurs d'activité en 2021.

TABLE VI. Répartition des installations et activités par départements et par secteurs d'activités

Départements	Secteur médical			Secteur industriel			Secteur de la recherche		
	Eff[a]	Dec[b]	PCR[c]	Eff	Dec	PCR	Eff	Dec	PCR
Alibori	3	3	3	3	2	2	0	0	0
Atacora	5	3	3	0	0	0	0	0	0
Atlantique	10	6	6	0	0	0	0	0	0
Borgou	8	6	6	1	1	1	0	0	0
Collines	4	3	3	2	1	1	0	0	0
Couffo	7	6	6	0	0	0	0	0	0
Donga	3	0	0	0	0	0	0	0	0
Littoral	24	11	11	3	2	2	5	2	2
Mono	3	2	2	2	0	0	1	0	0
Ouémé	11	4	4	3	0	0	0	0	0
Plateau	3	1	1	2	1	1	1	0	0
Zou	5	1	1	8	0	0	0	0	0

Total	86	46	46	23	7	7	6	2	2

[a] Effectif, [b] Déclaration, [c] Personne Compétente en Radioprotection

A la date du 15 octobre 2021, l'ANSR a dénombré quatre-vingt-une (81) sources de rayonnements ionisants dont soixante-quatorze (74) générateurs de rayons X et sept (07) sources radioactives.

La figure n°1 présente la distribution des générateurs de rayons X selon la valeur de leur tension électrique maximale et la figure 2 montre leur répartition en fonction du matériel de filtration inhérente.

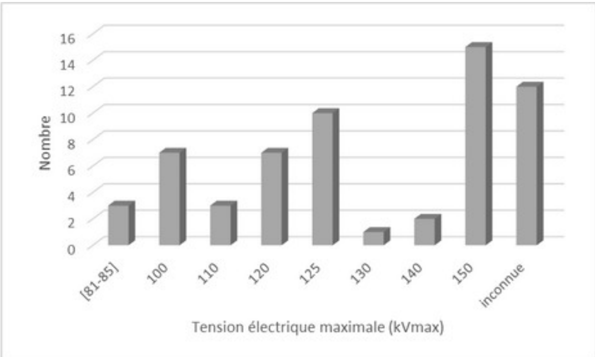

Fig.1. Répartition des générateurs de RX déclarés au 15 octobre 2021 selon leur tension électrique maximale

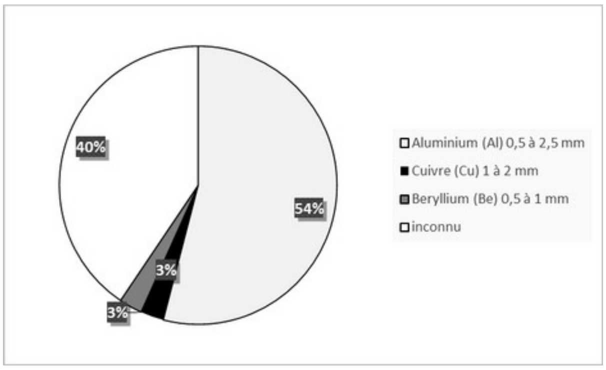

Fig.2. Répartition des générateurs de RX déclarés par matériel de filtration inhérente

L'analyse des figures 1 et 2 montre que la différence de potentielle (kV) maximale de ces générateurs de rayonnements X varie de 150 kV à 35 kV. La filtration inhérente est assurée par l'Aluminium (Al), le Cuivre (Cu) et le Béryllium (Be) dont les épaisseurs varient respectivement de 0,5 à 2,5 mm, de 0,1 à 1 mm et de 0,4 à 1,5 mm. La tension électrique maximale n'a pas été précisée pour 40% des générateurs de rayons X.

La figure 3 présente une distribution des générateurs de RX déclarés selon leur ancienneté.

Ce graphique montre que le parc radiologique du Bénin est vieillissant. L'ancienneté des générateurs est méconnue dans vingt pourcent (20%) des cas. Cinquante et un générateurs de RX (68,92%), soit plus des 2/3 d'entre eux sont vieux de plus de 10 ans.

Par ailleurs, la catégorisation des 7 sources radioactives déclarées à l'ANSR au 15 octobre 2021, a permis d'identifier 2 sources de catégorie 2, 1 de catégorie 3, 2 de catégorie 4 et 2 de catégorie 5. Aucune source de catégorie 1 n'a été déclarée dans les installations à la date du 15 octobre 2021.

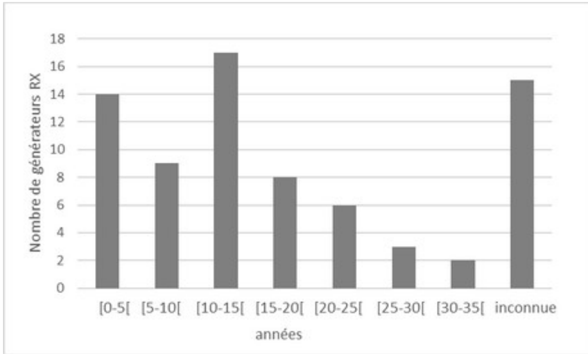

Fig.3. Répartition des générateurs de RX déclarés au 15 octobre 2021 par ancienneté

Le tableau III présente la liste des déclarations de matières nucléaires soumises à l'AIEA en 2021 en vertu des accords de garantie.

TABLE VII. DECLARATIONS SOUMISES A L'AIEA EN VERTU DES ACCORDS DE GARANTIE

Date de déclaration	Articles du Protocole additionnel concerné	Champ d'application
26 février 2021	3d	
26 février 2021	3d	
26 février 2021	3a	
26 février 2021	3b	Mise à jour annuelle
26 février 2021	3c	Déclaration annuelle des importations et exportations de matières nucléaires
26 février 2021	3e	Déclaration annuelle des déchets radioactifs de niveau intermédiaire et élevé
26 février 2021	3d	
26 février 2021	3d	
26 février 2021	3d	
04 mars 2021	3d	
29 mars 2021	3b	Mise à jour annuelle
29 mars 2021	3c	Déclaration annuelle des importations et exportations de matières nucléaires
29 mars 2021	3e	Déclaration annuelle des déchets radioactifs de niveau intermédiaire et élevé
27 mai 2021	3d	
27 août 2021	3d	

C. Les actions réglementaires réalisées en 2021

Dans l'exercice de ses prérogatives, l'ANSR a délivré des autorisations, inspecté des installations et prononcé des sanctions administratives prévues à l'article 54 de la loi 2017-29 du 15 mars 2018 [1]. Ces actions réglementaires consistent en 20 autorisations dont 2 agréments, 9 autorisations d'importation, 6 autorisations de transport de matières radioactives et 3 autorisations de détention et d'utilisation de sources radioactives. Vingt-neuf (29) installations ont été contrôlées et 2 installations ont été rappelées à l'ordre aux fins de se mettre en conformité avec les textes en vigueur.

D. Le profil du Bénin sur la plateforme RASIMS de l'AIEA

La plateforme du Système d'information des Autorités réglementaires (RASIMS) mis à la disposition des Etats par l'AIEA évalue les avancées dans les aires thématiques de compétences de l'Agence. Cette plateforme est organisée en 7 aires thématiques.

La figure 4 présente le profil RASIMS du Bénin en 2021.

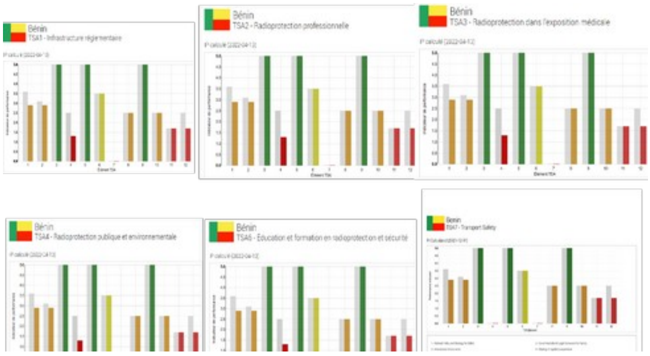

Fig.4. Représentations graphiques du profil du Bénin sur la plateforme RASIMS par aires thématiques

XXV. Conclusion

En septembre 2019, le Bénin a ratifié tous les instruments juridiques internationaux permettant de garantir la sûreté radiologique des pratiques utilisatrices de rayonnements ionisants et la sécurité nucléaire des installations disposant de sources radioactives ou nucléaires. L'ANSR a été rendue fonctionnelle depuis septembre 2020 pour réglementer ces pratiques et installations dans tous les secteurs d'activité. Un an après son opérationnalisation, l'ANSR a amorcé l'établissement du registre national des sources après avoir sensibilisé les exploitants des installations sur leurs responsabilités et formé les Personnes Compétentes en Radioprotection (PCR) de ces installations. La finalité de ces actions est de garantir la sûreté radiologique des pratiques et la sécurité des sources de rayonnements ionisants et installations associées.

Remerciement

L'ANSR remercie ses partenaires privilégiés, à savoir AIEA, US-DOE, etc. qui ont contribué activement, à travers leur appréciable assistance technique, aux avancées notables décrites dans ce manuscrit au cours de sa première année d'exercice.

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Small Modular Reactors – Economics, Safety, Advantages and Challenges

Jan Bartak
NucAdvisor
Paris, France
jan.bartak@nucadvisor.com

Gianni Bruna
NucAdvisor
Paris, France
gianni.bruna@nucadvisor.com

Gérard Cognet
NucAdvisor
Paris, France
gerard.cognet@nucadvisor.com

***Abstract*— The attractivity of SMRs (Small Modular Reactors) compared to traditional large-size Gen III/III+ reactors resides in their higher safety, versatility, flexibility, ability to provide a broader range of energies and energy services compared to pure electricity generation and hence be a major contributor to the decarbonization of a broad range of industrial and economic activities. Advanced SMRs bear the promise of ‘game changers’ in terms of high intrinsic safety, new functionalities, high proliferation resistance and, importantly, expected lower capital costs. However, despite the significant progress made in the development of various SMR technologies in recent years, considerable development efforts are still necessary. The paper presents a general overview of the main development drivers of SMRs and their implications in terms of safety advantages and challenges. The main safety features of different families of SMRs (light water cooled, high temperature, fast neutron, and molten salt) are then reviewed without bias and independently of any of the designers.**

Keywords—energy, nuclear, small modular reactors, safety

XXVI. Introduction

Because of their versatility, flexibility, ability for cogeneration and attractive safety features, SMRs (Small Modular Reactors) are being considered by many countries as a potential and viable option to replace traditional thermal power plants, to provide a source of heat for heating and industrial application, for the production of low-carbon hydrogen. They could play an important role in reducing CO2 emissions. SMR designs often take advantage of overall system simplification. Due to their smaller reactor cores, very large water inventories and lower power densities, Light Water Reactor technology SMRs, which are the most mature SMR concepts, may benefit from reduced shielding requirements and reduced or eliminated offsite emergency planning zones. Inherent passive safety systems could also provide some SMRs with greater and, in some cases infinite coping times in case of a loss of offsite power. Some SMRs are designed to be installed below ground level resulting in higher physical protection and protection from external hazards. Advanced SMRs use reviewed cooling systems or fuels (molten salts, liquid metals or helium gas) and bear the promise of ‘game changers’ in terms of high intrinsic safety, new functionalities, high proliferation resistance and, importantly, expected lower capital costs mainly due to design simplicity and the absence of high pressure and lower generation costs. These features and the diversity of applications (electricity plus heat and/or hydrogen) explain that there are more than 70 different design concepts under development around the world with different technology and licensing readiness levels. Despite the significant progress made in the development various SMR technologies in recent years, considerable hurdles still need to be overcome, in particular in relation to safety assessment and licensing.

Looking at the historical evolution of nuclear power reactors, the long-term trend so far has been to increase the size of the reactors to maintain their economic competitiveness through economies of scale. However, over the last five years, advanced reactor concepts, among which SMRs (Small Modular Reactors), have progressed faster than anyone predicted ten years ago, and it is highly likely that over the next ten years we will see the construction and operation of several FOAK (First Of A Kind) SMRs and the development of a global supply chain to support them.

One of the reasons for this keen interest is that SMRs could become one of the main drivers of the deep decarbonisation of the global economy, thanks to their versatility, flexibility, and ability for cogeneration (electricity, heat for heating and industry, water desalination, hydrogen production). This interest and the diversity of applications (electricity in remote areas, low and high enthalpy heat for heating and industry, water desalination, hydrogen production) explain that, according to IAEA [1], there are more than 70 different design concepts under development around the world with different technology and licensing readiness levels. Moreover, most SMR designs rely on higher levels of intrinsic safety and/or passive safety systems compared to Gen III/III+ LWRs which should facilitate their acceptability by the public and allow their operation within existing industrial sites or closer to large cities.

Despite this progress, most of the SMR designs still must overcome significant technical hurdles in domains such as nuclear fuel reliability, materials behavior, component manufacturing and more globally in their safety assessment and licensing. With the exception of the Russian barge-mounted SMR, the first of which is already operational, all the other SMR designs have still to be licensed in a context where the existing regulatory frameworks have to be reviewed and, presumably modified to some extent, to make them applicable to this new type of reactors.

XXVII. The SMR concept

The SMRs are relatively low power nuclear reactors (typically up to 300 MWe) based on a modular way of construction. That means the sub-systems and systems are built on modules in factory then transported to be assembled on site and on a multi-unit NPP (Nuclear Power Plant) concept, which enables to incrementally extend the power of the overall plant.

A. Economic fundamentals of SMRs

The SMR concept has been around for decades but it did not materialise as an industry. Today, SMRs present some key economic drivers which make them attractive to replace fossil fuels for electricity production and decarbonisation of hard-to-abate industrial sectors. These key economic drivers are (see Figure 1 below) [2] [5]:

- Modularisation and factory build: It is estimated that 60-80% factory fabrication levels are possible for SMRs.
- Design simplification: Passive mechanism improvements and greater design integration would reduce the number of components and result in containment building savings and facilitate ease of operation and maintenance.
- Standardisation: Compared to large reactors, the lower power output and smaller footprint of SMRs reduces the need to adapt to local site conditions.
- Regulatory and licensing harmonization which should make easier access to a global market.

From an economic and financing perspective, the small size of SMRs should largely facilitate the attractiveness of investment and significantly reduce the real or perceived investment risks. The important characteristics of SMRs from an investment perspective are the following [2] [3]:

- Lower capital costs: the smaller size of SMRs leads to lower overall capital costs, and related lower financing costs. Further, the complexity and size of the on-site structures needed will be reduced, most of the SMR plant can be built in a factory or shipyard and delivered to site. This can reduce construction times by half or more, reducing significant plant financing costs. Light water SMRs will benefit from the large experience accumulated in marine propulsion and capitalise on modular construction experience and hundreds of reactor-years of operating experience. However, cost optimisation was not always the key objective of the designers of these reactors, so considerable efforts will be needed to beat the diseconomy of scale and achieve competitive costs per MW installed. Non-light water SMRs also bear the promise to reduce the capital costs significantly. They address the cost issue by eliminating water from the cooling process, using coolants with different characteristics and using inherent safety strategies, eliminating the need for pressurized containment and redundant cooling equipment, radically reducing the total plant mass of concrete and steel.
- Smaller upfront investment: the lower total overnight costs of SMRs will also result in lower upfront development costs, making project development easier and accessible to private and public developers with limited financial resources.
- Investment scalability: in stable market conditions or highly regulated environments, the SMR modularity translates into the possibility to decide between sequencing the investment (and the start of revenue earning of each module) over time or build multiple modules in parallel (higher one-time investment – similar to building a large reactor).
- Investment flexibility: in uncertain or highly volatile market conditions, SMR modularity translates into flexibility. The shorter construction and commissioning times of individual modules allow to adapt more flexibly to the changing market conditions and adjust further investment to reflect new market conditions.
- Shorter and more certain construction schedule: less than 20% of the costs of a large Gen III reactor are connected to the cost of the nuclear reactor itself and power production equipment. Most of the cost comes from the construction of large containment structures, cooling equipment, site infrastructure, and financing costs during lengthy construction times. SMRs could be built in 3 to 5 years, their lower overnight costs resulting in reduced labour and site costs. The standardised SMR 'product' will allow for much higher construction schedule certainty.
- Lower risks result in cheaper financing: the lower capital costs, standardised nature of the SMR, shorter construction times and lead times result in lower completion risks, lower interest rate exposures, reduced uncertainties of data entering the discounted cash flow model. The investor will be willing to accept lower internal rates of return on equity and lenders will offer lower interests on debt.
- Self-financing opportunity: staggered deployment of SMR modules allows to produce revenue from the first modules that can be used for financing of the subsequent modules, reducing the need of fresh equity and debt injections.

Public acceptance is another key challenge for SMR deployment, though it may differ significantly from country to country. The claimed intrinsic safety characteristics of SMRs are no doubt favorable to obtain public acceptance in an energy-constrained world. While much attention related to SMR development is duly focused on their competitiveness, the demonstration of SMR safety, reduced waste generation and proliferation resistance will be crucial for their public acceptance.

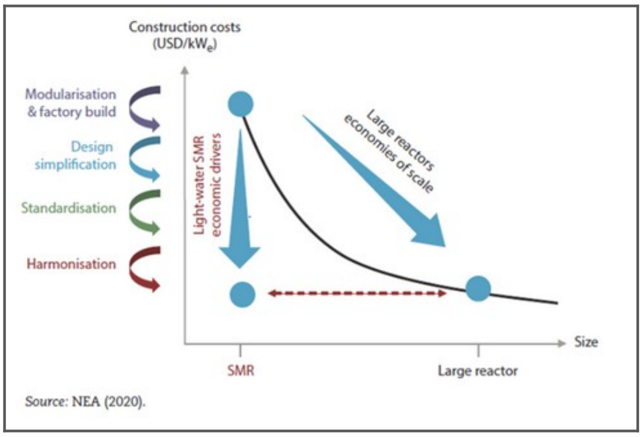

Fig 1: SMR economic drivers compensating the diseconomies of scale Source: (NEA2020)

B. *Safety requirements for SMRs*

The safety criteria are aimed at preserving the safety functions of the nuclear installations despite failures of materials and components and/or human inadvertent and/or malevolent behaviour. Accordingly, the same (and well known) main safety functions of conventional reactors must be transposed to SMRs to guarantee their safe and secure operation in any circumstances and at any time in their life from design to decommissioning.

The safety of each SMR design will rely on its inherent or specific provisions which must be carefully examined. SMR designs may bring forward opportunities to enhance - at the early design stage - the robustness and independence of the Defence in Depth levels resulting in higher resilience compared to the conventional Gen II&III reactors for different types of hazards.

As SMRs may use shared systems because of their compact configuration and proximity of modules, the selection of initiating events should include in-depth consideration of common-mode initiators. Moreover, the capacity of mitigation of the consequences of severe accidents is to be enhanced for SMRs to fulfil the requirement of avoiding any need for evacuation of the population in the vicinity of the plant site.

C. *All SMR designs target and share a high level of safety*

In relation to the SMRs small size, the implementation and effectiveness of advanced safety features is strongly dependent on the arrangement of components that requires a suitable optimization of the overall architecture, through conservative design and a risk-informed driven approach. The development of SMRs offers multiple opportunities to enhance safety. This objective may be achieved for any SMR design benefitting from several features and/or opportunities which are common and shared by most designs, such as:

- Low (in absolute terms) fissile material inventory, which leads to low residual heat, a small source term, and overall low releases in case of major accidents.
- Reduced overall cooling requirements, allowing for a wide selection of sites, through a suitable optimization of modules number per site.
- Feasibility of the IVR (In Vessel Retention) of the molten core, which has a higher probability of success for SMRs considering the lower fissile inventory, and which is an important element of their overall safety demonstration.
- Strong plant integration, which can turn out to be beneficial for a safe and secure operation (the integrated design allows a direct coupling among main components, e.g., the steam generators with the vessel, the primary pumps with either the vessel or the steam generator etc.). That enables eliminating by design any risk of large breaks, which are a major threat in large size loop reactors.
- Possibility for LW (Light Water) SMRs of a core control without soluble boron, which eliminates the RIA (Reactivity Initiated Accidents) likelihood due to dilution error (including the inadvertent start-up of pumps in steady-state conditions).
- Inherent compactness of SMRs that enables minimizing the risk engendered by most external aggressions and hazards by underground construction or even by submersion (immerged NPP). That is also advantageous in view of the resistance to earthquake.
- Reduced plant size, that may be really advantageous because of:
- the increased resistance to earthquakes,
- the smaller cross-section vs. impacts of missiles of any kind,
- the possibility to ensure a better accessibility for inspection, maintenance, and repair,
- the adoption and operation of natural convection, when possible, which increases the robustness vs. pump incident of any kind.
- Low pressure of certain designs which results in system simplification, exclusion by design of all accidents caused by high pressure, easy factory fabrication, and expected cost reduction.
- Use of simpler components, and the presence of fewer dependencies (that simplify the manufacturing, validation and, eventually, the licensing processes).
- Simplification of the systems that effectively prevents from the presence of common modes.
- Adoption of convenient operation / replacement requirements and procedures, depending on the design features.

As already emphasized, in close relation to the SMRs small size, the implementation and effectiveness of advanced safety features is strongly dependent on the arrangement of components that requires a suitable optimization of the overall architecture. In some cases, certain fast-developing accidents such as LOCAs (Loss of Coolant Accidents) in LW SMR can be inherently eliminated by design and operation.

These improvements may provide opportunities to ease the burden on operating staff and for more effective accident management and should therefore result in a more efficient and eased licensing process.

The assessment of such new and advanced reactor concepts, as well as the development of innovative materials, component and fabrication processes require the fulfilment of specific safety requirements. Such requirements would greatly benefit from international and multilateral regulatory harmonization.

More generally, the development of SMRs creates an opportunity but also calls for the necessity to develop harmonized safety requirements and to apply widely agreed methodologies in the licensing process, as mentioned in the WNA report "Facilitating International Licensing of Small Modular Reactors" [4].

The Memorandum of Cooperation on advanced reactor and SMR technologies between the US NRC and the Canadian Nuclear Safety Commission is an example to follow. In Europe, organizations such as ENSREG, WENRA, and ETSON should participate in the elaboration of such a set of recommendations. Also, the IAEA ongoing initiatives on SMR licensing are very important and very welcome.

D. … But many challenges are still to be overcome

As said, most SMR designs incorporate inherent and/or passive safety features. This enables the plant to either efficiently face malfunctions and aggressions, or to passively evacuate the residual heat and allot time for recovery. The reduced power and extended adoption of passive systems and/or off-operated systems (e.g., in the case of sub-marine concepts) should facilitate severe accident management, e.g., by providing extended grace periods in case of station black out, as well as to the emergency preparedness and response.

However, demonstrating safety relying on inherent physical phenomena and passive systems is often a challenging task. Specific care must be put in the development of safety requirements criteria and rules for their assessment, including:

- Reliability of activation and raise to required capacity.
- Reliability to perform the assigned function.
- Dependence on external energy sources for initialization and execution of the assigned function.
- Physical phenomena and the environmental conditions that could lead to the loss of the assigned function.
- Uncertainties and margins, because the combination of interfacing inherent and passive design features can engender cliff-edge effects. Accordingly, specific care should be paid to integrated test activities during the design and the commissioning phases.
- Multi-unit concept which increases the risk of propagation of incidents and accidents among the units.
- Methodology for the evaluation of performance and its integration into Probabilistic Safety Assessment (PSA).
- Specific requirements for Severe Accident Management and Emergency Preparedness Plan, because the accident progression at the neighbouring units can hamper the management activities at the unit the transient originates from.
- Moreover, the following specific topics shall be accurately and in-depth addressed as preliminary considerations for licensing:
    - The safety requirements must be accurately revised and updated to account for the modular assembling and the remote construction and qualification of equipment.
    - The SMR designs should incorporate redundancy, diversity and, where practicable, physical separation for safety systems to mitigate common cause failures. Moreover, exclusive adoption and deployment of passive safety systems merit specific care.
    - The SMR design can profit from the combination of passive and active systems to ensure the safety functions, which can improve resilience to common cause failures.
    - Any combination of active and passive safety systems matching the Defence in Depth and the safety design principles is acceptable. Nevertheless, a suitable prioritization should favour inherent characteristics and passive features or continuously operating systems over systems that need actuation.
    - Licensing methods should be harmonized to anticipate the possible incremental extension of the installed capacity of the target plant through the addition of modules.

XXVIII. SAFETY CHARACTERISTICS OF THE MAIN SMR TYPES

The family of SMRs includes an exceptionally large diversity of concept designs, each of them presenting specific safety advantages with respect to conventional large power reactors.

In the following sections, the safety features of the main SMR families are addressed based on advantages vs. points of vigilance approach.

A. Light Water SMRs (LW SMRs)

The LW SMR concepts are evolutionary variants of mature light water Generation II and III reactors and may benefit from decades of operating and safety experience. They represent approximatively half of the SMR designs currently under development. These LW SMRs are moderated and cooled by ordinary water, of pressurized or boiling water type, for electricity or heat generation. They can also be of pool type reactors for district heating.

The PWR (Pressurized Water Reactor) NSSS (Nuclear Steam Supply System) may be either an integral one, with the complete high-energy primary system contained inside a single pressure vessel, or a compact design with steam generators connected directly to the reactor pressure vessel. Primary cooling flow may be achieved by natural circulation (with the steam generators above the core) for low power reactors, or by forced circulation for higher power reactors with primary pumps (ex: leak-tight canned motor pump or wet coil pump), with natural circulation capability in emergency conditions.

The BWR (Boiling Water Reactor) NSSS may be cooled by natural circulation of the coolant, thus eliminating the recirculation pumps, allowing for a simplified and compact reactor pressure vessel and containment, and simplified reactor internals and systems.

LW SMRs have similar operating conditions and fuel arrangements, with the use of uranium oxide fuel with enrichment below 5%, which may facilitate the licensing process. The core excess reactivity may be controlled using Gd2O3 as burnable poison in specific fuel rods and movable absorbing elements, thus avoiding adoption of soluble boron.

Safety features - potential advantages

Among safety advantages, benefiting from the small size and depending on each specific design and power level, different options may be implemented such as:

- Passive management of accident scenarios with no need for operator's action, or with simple diagnosis and implementation of diversified systems.
- Large reactor coolant inventory which may provide inertia versus power transients.
- Adoption of a boron-free operation which may provide large and constant moderator counter-reaction and avoid boron dilution accidents.
- Integrated reactor coolant architecture which is likely to reduce the maximum LOCA break size, thus providing more time for coping with LOCA.
- Internal CRDMs (Control Rod Drive Mechanisms) which avoid any penetration of the reactor vessel, thus preventing from inadvertent road extraction and ejection accidents.
- Metallic submerged containment which may provide passive cooling, or air-cooled containment.
- Small core in large vessel which may facilitate the in-vessel retention strategy.
- Possible use of passive systems, depending on design: decay heat removal system, emergency core cooling system, containment, air cooling system, reactor automatic depressurization system, meeting criteria of single failure, independence, diversity, or multiplicity.
- Direct current power source to support accident mitigation for extended period, along with auxiliary power units to recharge the battery system.
- Load follow operation using grey rods with lower worth to avoid adjusting soluble boron concentration, which results in a substantial reduction in wastewater generation and treatment.
- Passive hydrogen recombiner system installed to control the hydrogen concentration in containment.
- Safety features to prevent criticality risks: sub-criticality with clear water with the most efficient absorber stuck in upper position.

Safety features - potential points of vigilance depending on any specific design

- Small size of equipment and / or the compactness of equipment can create difficulty for non-destructive testing.
- Small distance between the core and the vessel may induce larger radiation level on the vessel which can turn out penalizing for metal embrittlement.

Very high compactness of the architecture can reduce the ease of the inspection and repair operations.

B. High Temperature SMRs (HT SMRs)

The HT SMRs enjoy all the advantages of the SMRs, including the high modularity and the economic competitiveness, jointly with those of the HTGR (High Temperature Gas Reactor) / VHTGR (Very High Temperature Gas Reactor) concepts belonging to Gen IV, such as inherent safety, fuel economy, low waste volume, as well as high resistance to nuclear proliferation and capacity to incinerate both plutonium and minor actinides.

The thermal HT SMRs are intrinsically safe by design, due to their very low power density, their very long prompt neutron lifetime, which excludes any prompt reactivity surge, and the huge amount of moderator surrounding the core, which enables the passive evacuation of the residual heat without external intervention and addition of complementary systems.

Safety features - potential advantages

- Fuel margins of the HT SMR are very high, therefore the entire mission of fuel products retention is accomplished by the TRISO particles.
- Helium, the gas used for cooling, is an inert, radiologically transparent single-phase gas, avoiding boiling or flashing. It does not react chemically with the fuel and the reactor components. Though it has a propensity to escape, it is quite easy to control the pressure in the reactor.
- Moreover, the HT SMR has some other intrinsic safety features:
    - in case of Reactivity-Initiated Accident (RIA), the system does not undergo a sudden exponential increase of power, due to the very long prompt neutron lifetime,
    - in case of major accidents, the reactor core does not melt down, because all the heat dissipates passively into the environment, whatever the scenario, the plant has no need for active safety systems to remove heat. Additionally, it does not need outside support (even electricity) to operate safely.

Safety features - potential points of vigilance depending on any specific design

- Physical features of the HT SMR make it sensitive to air and water ingress from the external environment, which can initiate and feed-up severe accidents.
- For some concepts, the high temperature and / or the presence of salts in the coolant demand for extensive qualification of the materials resistance to corrosion.

- As it is the case for all SMRs, the multi-unit concept of the NPP increases the risk of propagation of incidents and accidents among the units.
- Underground operation, if implemented, can turn out to be risky in case of flooding. Moreover, the system can be sensitive to extreme weather conditions.
- TRISO particles are not perfectly tight and allow leakage of some low yield fission products, such as Ag, during long term operation at very high temperature.
- Remote operation can be sensitive to cyber-attacks.
- Real size experience remains limited.

C. Molten salt SMRs

The concept of Molten Salt Reactor was originally developed at Oak Ridge National Laboratory (ORNL) in the '60s, and three experimental MSRs have already been constructed. Nowadays, several MSRs are under design, and preliminary licensing activities are going on in different countries, including Canada, United Kingdom, and the United States.

Molten Salt SMRs adopt an advanced reactor technology, which belongs to Generation IV. The MSRs generally use molten fluoride or chloride salt, both as liquid fuel and coolant. Designed either in thermal or fast neutron spectrum, MSRs aim for long fuel cycle of up to 150 months, online refuelling (with addition of fuel under molten salt form, and on-line fission products cleaning) and continuous operation. Enrichment of fuel spans from less than 5% up to 19.7%.

The vast majority of innovative MSR designs are not yet industrially implemented; a few are at demonstration stage and most of them at R&D level, with an industrial maturity which is still to be confirmed. The safety objective with the SMR designs is to achieve high inherent safety, and a walk-away safe nuclear power plant.

<u>Safety features - potential advantages</u>

- Exclusion of fuel fusion.
- Inherent safety features associated to the salt expansion. When the temperature rises, the liquid expands and the average mean free path of neutrons increases, thus inducing a negative reactivity feedback.
- Very high level of inherent safety thanks to an integrated, pipe-less, fail-safe systems architecture.
- Near-to-zero reactivity swing during the cycle, which prevents the core from any risk of major RIA.
- Thermally and chemically stable low-volatile fuel-coolant mixture, inert at high temperature, which allows low pressure operation and eliminates any need for large containment.
- Absence of fuel structure or cladding, which prevents the fuel from being subject to failures because of high burnup or mechanical damage.
- Molten core provides enhanced safety, because it avoids any risk of severe consequences to the vessel integrity and a possible fission products release.
- No need for operator action, electricity, or externally powered mechanical components, to assure the primary safety functions of control, cooling, and containment.
- Availability of all required control and heat sink functions, which eliminates any dependence on support systems, valves, pumps, controls, or operator actions for cooling.

<u>Safety features - potential points of vigilance depending on any specific design</u>

- Relatively high design and operation complexity, including the on-line continuous operation of the salt cleaning function.
- Cumbersome reactor overall lay-out.
- Relatively high vulnerability to hazards, including flooding and earthquakes.
- Complex inspection, repair, and replacement of components due to high radiation levels.
- Relatively low industrial maturity.

Likelihood of hurdles in the licensing process, due to the unusual reactor features and operation mode.

D. Fast neutron SMRs

Global interest in fast reactors has been growing since their inception in the 1960s because they can provide efficient, safe, and sustainable energy for the long-term nuclear energy resources as well as contribute to decrease the burden of nuclear wastes, mainly long-lived minor actinides. In addition to the current fast reactor operation or construction projects underway, several countries are engaged in intense R&D programs for the development of innovative, Gen IV, fast reactors, as proposed by the Generation IV International Forum. They include three fast neutrons concepts: the SFR - Sodium Fast Reactor -, the LFR - Lead (or Lead-Bismuth) Fast Reactor - and the GFR (Gas Fast Reactor), as well as the MSR (Molten Salt Reactor) which can be declined both in a thermal and a fast neutrons version (see section III.C).

While Gen IV-based SMR designs do not enjoy the long operating and regulatory experience of LWRs, they benefit from an extensive history of past research and development and the operating and regulatory experience of SFRs in some countries, which developers and regulators may rely upon.

The most mature Gen IV designs are the metal-cooled systems with some units currently in operation or under construction, which may also provide specific opportunities for non-electric applications due to their high outlet temperatures as well as their advanced fuel cycles. Among these three systems (alkali metals, metal, and gas), the SFR (Sodium Fast Reactor) is, by far, the most widely spread-out technology worldwide. It has an acknowledged maturity due to the numerous constructions and because it accumulated years of operation in several countries, including France, Russia, China, and India.

Combining the specificities of fast neutron reactors (breeders or burners) with the benefits of SMRs in terms of standardization, modularity and power generation flexibility could turn-out quite attractive for some countries and in specific geographic conditions (isolation, insufficient grid capacity…). That explains why several SMRs designs are under advanced development worldwide, e.g., NATRIUM, ARC-100, and GE-Hitachi (PRISM). In Russia, the Brest-OD-300 (LFR) received the construction license in February 2021; the prototype will be built in Seversk.

Safety features - potential advantages

The safety advantages of the fast neutron SMRs basically depend on their nature and design (and mainly on the coolant features and properties), but, overall, they share some advantages which are inherent to their size and architecture, such as:

- The small fissile inventory, which turns out advantageous both in normal and degraded operation, as well as in case of accidents. Moreover, it reduces the production of waste (i.e., long-lived actinides).
- The small size of the core which contributes to enhanced safety both in case of RIA and coolant void transients, due to the increased neutron leakage (to reduce the risk of reactivity increase).
- The neutron system behaviour which is close to the fundamental mode (the reduced core size and the high leakage contribute to the core stability through a very quick elimination of all flux harmonics engendered by the perturbations) in any circumstances.
- The reactivity swing over the cycle, which is quite low, thus reducing the needs for excess reactivity compensation.
- The likelihood of the IVR (In Vessel Retention) of the melt core in case of severe accident, due to the small fissile inventory, the low power and the vessel design.
- The passive safety features, depending on the design.
- The coolant which possesses very good thermal inertial capacity and thermal properties (good conductivity and high boiling temperature).

Safety features - potential points of vigilance depending on any specific design

The fast reactor SMRs share the main drawbacks of their large-scale reference, such as:

- For all concepts, the fuel design and qualification which requires either specific irradiation capacity in high flux facilities, which are poorly available, or long per assembly in-reactor testing.
- For a large majority of concepts, the likely difficult periodic in-service inspection due to the integration of the design.
- For SFRs, the violent exothermic reaction of sodium with water and air, the risk of core melt in case of blockage of the flow in the subassembly and the risk for either a sharp increase or a stagnation of reactivity in case of loss of coolant.
- For LFRs: the corrosion and abrasion of fuel and components due to the high operating temperature, due to the melting point of the coolant metal.
- For GFRs: the difficulty of evacuation of the residual power in case of severe accidents, which needs specifically engineered systems.

XXIX. Conclusions

While long-term forecasting of the evolution of energy systems and energy transitions is a perilous exercise, it seems quite difficult to imagine future low-carbon energy systems without reliance on nuclear power.

Even though the large Gen III/III+ reactors have now gone through their initial teething troubles and are being successfully deployed, demonstrating their reliability and enhanced safety, their development remains a considerable undertaking for any country, requiring long and thorough preparation and considerable human, and financial resources per unit. Also, their GW-scale capacity and large size may be an impediment for use in smaller grids or in locations to which transportation of the large components may be difficult or impossible.

In this context, Small Modular Reactors (SMRs) could be the future of nuclear industry, with the potential to provide energy without greenhouse gas emissions to countries or remote communities and for a wide range of applications, from electricity generation whatever the grid size or off-grid, to various uses of heat for industrial and domestic applications, including the production of hydrogen to decarbonize hard-to-abate industrial sectors and heavy transport.

High inherent safety, favourable design and operational characteristics, compactness and modularity allowing for a high level of standardization, enhanced capacity to face external aggression and hazards, potential resistance to proliferation, reduced investment per units, serial factory production of modules, shorter construction times - all these features will allow SMRs to effectively contribute and positively solve the present-day challenges of nuclear power, including its wider public acceptance and the acknowledgement of its key role on the path to net zero carbon emissions. However, the SMRs promise must be evaluated with lucidity and rigor. This is especially true for their safety demonstration, the importance of which cannot be overstated. Moreover, global harmonization and coordination of licensing approaches is crucial for SMRs large-scale deployment.

Drawing from the experience of NucAdvisor experts in nuclear energy and nuclear safety, this paper provides an overview of the promising economic and safety characteristics of the different SMR concepts and the challenges that need to be overcome before their industrial deployment. Moreover, offering informative safety-grounded arguments to support the decision-making process in view of the development and the deployment of SMRs, it should be helpful to stakeholders, potential clients, and partners both in developed and emerging countries.

Acknowledgment

The authors gratefully thank the expert-partners of NucAdvisor, in particular Noël Camarcat, Jacques Chenais, Michel Debes, and Jean-Philippe Girard, who reviewed this paper.

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Your road to nuclear: How to deploy your nuclear energy options?

Henri Zaccai
Partner Road-to-Nuclear
Belgium
henri.zaccai@gmail.com

Jean-Jacques Gautrot
Partner Road-to-Nuclear
France

Sylvain Hercberg
Partner Road-to-Nuclear
France

Luc Van Den Durpel
Partner Road-to-Nuclear
Belgium

***Abstract*—Unlike other forms of source of electricity generation, developing and deploying an electronuclear production facility/program requires a large investment and a major undertaking resulting into a program spanning more than one century from initial decision until final waste management. But such a long-term engagement towards electronuclear also brings many socio-economic benefits well beyond the service of providing reliable decarbonized energy such as security of electricity supply, low cost of electricity, employment, …**

Various recommendations for such a nuclear energy program deployment have been largely documented by major international organizations (IAEA, WNA, OECD NEA, …). Such a deployment needs additional skills and capabilities from nuclear operators, suppliers, and various institutions. The experience from various countries operating hundreds of nuclear power plants will benefit those countries embarking into a nuclear program.

The Road-to-Nuclear Partnership, grouping four consultancy companies, provide such independent services based on lessons learned, and recommendations to provide all needed appropriate steps to implement an electronuclear program and the road towards the use of nuclear energy for electricity generation and other applications of nuclear science and technology. Defining a nuclear program demands a customized combination of energy and nuclear energy scenario analysis, technology and technical-economic assessment of options, a performing regulatory framework, clear prospects on fuel cycle and waste management, and the capability to execute major complex project management.

This paper will highlight recommendations regarding:

- **Nuclear energy program development and deployment.**
- **Down-selection of nuclear reactor technologies and associated fuel cycle and waste management options matching the projected needs in Africa.**
- **"How-to s" towards a nuclear program definition, initiation, and deployment.**
- **Road-to-Nuclear's services.**

Keywords—Nuclear Energy program, How-to

I. Introduction

Nuclear energy generation is complying with sustainable development principles and can thus be considered as an essential component of a sustainable energy future achieving four objectives:

- **Security of supply**: being a dispatchable electricity source, nuclear energy generation can provide electricity at any time and ensures the baseload supply of the electricity network.
- Nuclear generation ensures a **competitive supply of electricity**. Indeed, the last report (9th edition) issued by the IEA (International Energy Agency) and the OECD-NEA assesses the Levelized Cost Of electricity (LCOE) [1]. The report highlights two key points, investing in low carbon technologies is now more profitable than in fossil fuels based on a CO2 price scenario of US $ 30 / tCO2 and above. In this panel, nuclear appears to be the most competitive dispatchable low-carbon electricity generation technology.
- Nuclear energy contributes to the **reduction of CO2 emissions** from electricity generation, less than 10g CO2 per kWh, when emissions are 750 to 1000g CO2 per kWh for coal generation and around 350g CO2 per kWh for gas generation.
- Nuclear electricity generation comply with the **Sustainable Development Goals** [2, 3, 4, 5 and 6]. The Sustainable Development Goals, also known as the Global Goals, were adopted by all United Nations Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030 and beyond (UNDP). In practice, the Sustainable Development Goals lead to development of the economy, protection of the environment and social progress.

This paper will highlight recommendations regarding:

- Nuclear energy program development and deployment.

- Down-selection of nuclear reactor technologies and associated fuel cycle and waste management options matching the projected needs in Africa.
- “How-to’ s” towards a nuclear program definition, initiation, and deployment.
- Road-to-Nuclear’s services.

II. Nuclear generation in a Newcomer country

Complying with international recommendations to meet the climate change challenge is the responsibility for every country in the world. In general terms, electricity is tomorrow's most efficient final energy for the world:

- Every country needs a self-sufficient baseload electricity generation that nuclear energy can provide
- Electricity generation must contribute to meeting the challenges of sustainable development, as has been seen above: economic efficiency, environmental protection, and social responsibility

Regarding nuclear industry, safety is the primary concern of the operators and stakeholders. Nuclear energy is changing the future of the newcomer country for the best, thanks to the following features for the newcomer country

- Major contribution to security of energy supply
- Having a dispatchable production for a stable and competitive electricity generation
- Providing non-electricity energy services for water desalination, hydrogen production, district heating and process heat
- Keeping stable prices on the long-term. The impact of the nuclear fuel cycle economics changes in the LCOE is low (around 20%) compared to the one of fossil fuel (60 to 70%)
- Providing long-term human resources employment: launching a nuclear program in a newcomer country needs to develop and deploy dedicated human resources to ensure a sound and safe industrial and regulatory environment
- Developing high level technology industries: the newcomer country needs to develop its own national industrial and technological skills to avoid being fully dependent on foreign capabilities
- Moreover, addressing the environment issues, nuclear electricity generation meets several major challenges: compliance with of the local environment requirements, “zero carbon” generation, and pollution reduction

III. What are the phases needed to implement a nuclear program

Deploying a nuclear program in a newcomer country needs to fulfil a great number of conditions to be able to implement a nuclear generation safely and economically as stated above.

This paper proposes the following phases to achieve such a goal:

- Phase 1: Considerations needed to gather all elements before making the decision to launch a nuclear power plant program: this phase is devoted to ensuring the appropriate understanding and planning to the newcomer country. The duration of this phase is typically 1 to 3 years. At the end of this phase, the newcomer country is ready to take knowledgeable commitment.
- Phase 2: Preparatory work for the contracting and construction of a NPP after a policy decision has been made. The duration of this phase is typically 3 to 7 years. At the end of this phase, the newcomer country is ready to invite bids to negotiate contracts for the first of a NPP fleet
- Phase 3: This phase covers the activities to contract, license and construct the first NPP. The duration of this phase is typically 7 to 10 years. At the end of this phase, the newcomer country is ready to commission and operate the first of a NPP fleet

When looking at the cumulated time frame, it should be clearly mentioned that if Phase 1 is very well prepared, time will be spared during the subsequent phases 2 and 3 leading to an average global time frame of around 15 years.

The consulting services provided by the “Road-To-Nuclear” group of experts covers phase 1 and 2, the precise content of these phases is further detailed

A. Phase 1: mapping the options

The services of the Road-To-Nuclear partnership are geared towards the nuclear program success. The phase 1 includes the following considerations: energy planning, nuclear energy planning, designing nuclear program, defining Expression of Interest in compliance with the international obligations? This phase gathers all needed information to confirm the decision to go ahead.

1) Energy planning

This phase leads to **projected energy demand and supply scenarios** based on the forecast of socio-economic development (with national bank, planning office…). It covers the following considerations:

- **Energy technology anticipation**, i.e., which technologies and which investment/production cost are considered in the energy demand and supply scenarios
- **Infrastructure / industrial plan**, i.e. assessment of domestic industry development and deployment capabilities to maximise domestic advantages (capability/capacity building, education/R&D, workforce, broad economic impacts, …)
- **Financial market assessment**, i.e., domestic financial availability and assessment of foreign investment possibilities
- **Nuclear energy scenarios**, i.e. options for nuclear energy and identification and assessment of key critical success objectives/factors

2) Assessment of nuclear power plant options

The nuclear power plant options will be studied in order to match nuclear energy scenarios and cover the following topics:

- **Nuclear technology relevant**: what are the nuclear power plant technologies and options compatible with the energy planning.

- **Analysis of Supply chain options** for nuclear programme including all aspects from maximizing domestic skills development, capacity building, contracting leverage, …
- **Nuclear Law and Regulatory Framework**: the country will need to develop its own nuclear law and regulatory framework through the building-up of a National Safety Authority
- **Fuel cycle services and waste management** options analysis: the country will need to define its fuel cycle services (which fuel cycle options, which supplier, …) and implement a national waste management agency responsible for the waste management from cradle to grave.
- **Recommended Contracting Policy:** first assessment and proposed contracting objectives and key criteria indicators for contracting process

3) Delivery of Phase 1: Content of the prefeasibility study as expression of interest

The purpose of phase 1 is to address the main topics of the industrial framework in which the nuclear power program will be deployed and aims at gathering all needed elements to allow the owner to go ahead or not.

The Road-To-Nuclear Partnership has all skills and capabilities to support the newcomer country in drafting the **Deliverable Phase 1 report** which table of content is the following:

- The nuclear capacity installed power required considering the needs to be covered and the transmission grid network
- The technology options to be considered: type of reactor technology, typical size of the NPP, first selection of vendors, …
- International obligations to be fulfilled (safety, nuclear liability, waste management, spent fuel management, ….)
- The siting (environment study, …). A first selection of the potential sites considering important criteria (geology, cooling water, grid network size, …)
- The analysis of the network in which the power plant will be connected
- The fuel cycle options
- The economical assessment (LCOE, …)
- Nuclear skills development (education, training, R&D, …)
- Critical success factors for a nuclear program
- The financing scheme including risk analysis
- The actual implementation of the required national institutions and organizations besides the national nuclear operator/owner:
    - The Safety Authority
    - The Waste management organisation
    - (Possibly, a research centre entrusted with among others, training, and education capabilities)

At the end of this phase 1, the project owner can decide to go ahead or not with the nuclear program.

B. Phase 2: Developing Nuclear Planning

1) The Detailed Feasibility Study

The phase 2 is related to the development of the Detailed Feasibility Study and the Tender Specifications. It starts with the results of the previous prefeasibility study and the owner needs to invest in studies and assessments:

- Detailed Feasibility study including dialogue with stakeholders
- Detailing nuclear program development
- Nuclear technology options
- Accompany Regulatory, Skills development and Supply Chain development program
- Launching siting studies
- Map financial investment options

The owner will need to manage the tendering process and interfacing with interested tenderers and accompany down-selection process:

- Recommend governance and/or the selected business model of the nuclear program
- Verify compliance with international regulations
- Accompany implementation of the Safety Authority, waste agency, …
- Verify recommended Contracting Policy
- Define Specifications for tender documents

2) The Delivery of phase 2: decision to launch the program

The delivery of this phase 2 is to gather the main conditions necessary to launch the nuclear program.

The Road-To-Nuclear Partnership has all skills and capabilities to support the newcomer country in drafting the **Deliverable Phase 2 report** which covers the following topics:

- National nuclear law
- Respect of the international laws and treaties
- Safety authority in place, codes for licensing defined
- Owner's management core team in place
- Key features of the nuclear program
    - Capacity of the nuclear equipment
    - Grid network analysis
    - Codes, standards, and documentation for tenders
    - Terms and conditions of contracting schemes
    - Tendering process defined and list of main vendors ready for application (reactor, turbine, civil works)
    - Selection of candidate site(s) to host the nuclear power plant

- General schedule and first estimated investment cost of the program endorsed by the owner management's core team
- Financing scheme and investors call of interest
- Program risk analysis

- Education and training of teams to be involved in the program
- Public information

IV. The Road-To-Nuclear partnership: encompassing all facets of a nuclear program

The "Road-To-Nuclear partnership" gathers experts having already provided services to newcomer programs, such as:

- Nuclear market analysis for new expansion of nuclear program
- In-depth analysis of energy policy
- Full managerial and industrial support to the deployment of a nuclear program for newcomer countries
- Financial appraisal and contribution to the development of financing schemes (public/private financing models, financing analysis, project risks assessments, …) for the deployment of a nuclear program (Jordan)
- Support to deploy radioisotope production facility at research reactor in newcomer country
- Evaluation of local supply chain resources

The "Road-To-Nuclear partnership" is in perfect position to support the newcomers' countries to launch and deploy Phase 1 and 2 as presented here above thanks to their references described as follows:

- **Nuclear power plants (NPP)**
  - Nuclear plant offers and projects (construction projects in France, UK, China, Finland, Brazil and full offers for US, UAE, Poland, Jordan…)
  - Nuclear supply chain analysis in support of nuclear program and analysis of domestic industry capacity
  - Plant operation assistance and maintenance
  - Nuclear safety and operational security
  - Integrated risk management for NPP
  - Consistency with Sustainable Development Goals from building phase to operation
- **SMR and advanced nuclear technologies**
  - Market assessment of SMR project including global electricity mix study
  - Investor analysis for SMR development
  - Safety analysis of SMR and advanced nuclear power plant designs
  - Design studies for SMR in partnership with SMR-developers
  - Important note related to the SMR: SMR's are very attractive and modular nuclear power plants. However, it should be mentioned that there are still today a variety of technologies which are under study (with some cost and safety issues) and an industrial SMR will probably not be operational before 2030/2035
- **Safety, Security and Crisis management**
  - Nuclear safety and operational security
  - Crisis management for power plants
  - Crisis management in fuel cycle (French plants, international used fuel transport)
- **Fuel cycle**
  - Uranium to fresh fuel, (France, Canada, Japan, China, Belgium, US, UK, Germany, The Netherlands, Switzerland…)
  - Spent Nuclear Fuel and Radioactive Waste Management policy definition and technical-economic assessment of available management strategies
  - Assessment of market prospects for fuel cycle services
  - Setting-up and deployment of the whole financing schemes of the Belgian Waste management Agency
- **R&D**
  - One of Road-To-Nuclear partners has been Director of the Nuclear Energy Department of the French CEA
  - R&D-programme and prospective technology management for nuclear business leader
  - Creation of an R&D-center and definition of R&D-program for newcomer country in support to newbuild program
  - Strategic repositioning of nuclear R&D-organisation

V. Conclusion: The way forward

Developing and deploying an electronuclear production program requires a large investment and a major undertaking at the national country level resulting into a program spanning more than one century from initial decision until final waste management. Such a long-term engagement towards electronuclear requires implementation of an important infrastructure (industrial, regulatory, human, …) and brings thus a variety of broad socio-economic benefits well beyond the service of providing reliable decarbonized energy.

The Road-To-Nuclear Partnership expertise and references has the required experience and credentials to support the newcomers' countries in their will to develop their own nuclear power plant program.

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AFRICATOM? Lessons from Euratom to foster nuclear collaboration among African countries…

Marc Deffrennes
Retired Official of the European Commission (Euratom)
Former Senior Analyst OECD Nuclear Energy Agency
Professor High Engineering School Brussels ECAM
Member of the Scientific Council of SCKCEN
Secretary of the International Nuclear Societies Council
Founder of weCARE

***Abstract*—Energy availability is at the core of development and it must cope with challenges such as demography, climate change and scarity of resources. Nuclear energy is a zero carbon, very concentrated and now a mature technology, not yet widely used in Africa. Europe was in this situation 60 years ago and european countries decided to cooperate to tackle the challenges of using nuclear energy and therefore created Euratom.**

This paper presents the experience of the Euratom community as a source for reflection for African countries on a possible African Nuclear Energy Community. It also analyses the concept of sustainability as implying cleanliness, reliability and affordability on the long term, and its application to energy sources.

Keywords—Nuclear energy, sustainability, international cooperation, Euratom

VI. INTRODUCTION: WHY THIS IDEA?

The world is facing growing challenges. To name a few in the context of this paper: demography, climate change, energy needs and scarcity of resources… their combination possibly leading to increased poverty, social instability, and risks of conflicts if nothing is done. Tackling them will require strong and effective measures at global level in a multipolar world.

Nuclear energy is zero carbon, very concentrated, and the technology is mature. More than 400 reactors are in operation in the world, delivering around 10% of the electricity. In Europe, 120 reactors are providing around 20% of the electricity, and nearly 50% of the very low carbon electricity. Most of these reactors, the so-called generation II, have been built in the period 1970-1990. Time has come to think about their “long term operation” (LTO beyond the 40 years design lifetime) and about the building of new generation reactors (generation III and IV), including small and medium ones (SMRs).

Very few reactors are in operation, under construction or even planned in Africa, while everybody agrees that the continent will see the fastest growing population in the coming decades, with ever growing needs for energy. Nuclear, being carbon free, should therefore be considered as a key source of energy for African countries. But starting from scratch, on its own as an individual country, is not easy, even less when major (geo)political and economic interests are also at play, inside and outside the borders.

At this juncture in time, when the page is still rather blank, it might be of interest for African countries to deeply reflect on possible cooperation among those of them who want to engage in the deployment of nuclear plants. What happened in Europe 60 years ago under the Euratom Treaty might give some ideas, even if for sure it has not to be replicated as such. Lessons have to be drawn from the Euratom positive experience but also to avoid some pitfalls which sometimes were counterproductive versus the original goals of the Treaty. The idea of creating a strong African Community for the development and deployment of nuclear energy in the region, going further than intergovernmental agreements, might be worth to analyse.

This is what led to the proposed title Africatom – as Euratom was used for the European Atomic Energy Community in 1957. It is not the name which matters here, but the idea behind. Some international cooperation frameworks certainly already exist where African countries are collaborating. This paper simply aims at providing some information on the Euratom Community, as a source for reflection for African countries on a possible African Nuclear Energy Community.

VII. WHAT IS EURATOM

The Euratom Treaty [1], establishing the European Atomic Energy Community (EAEC-CEEA), was signed in 1957 by the six founding countries (Belgium, France, Germany, Italy, Luxemburg, Netherlands), at the same time they established the European Economic Community (EEC-CEE). Some years before the European Community for Coal and Steel (ECSS-CECA) had been created. All this resulted from the understanding that, to tackle the challenges of the post WWII, reconstructing the European continent required strong and effective cooperation instruments going beyond the pure interests of the individual countries. And energy was at the core of the endeavour.

It seems interesting today to launch the idea of Africatom, at a time when the challenges for Africa (and the world), while of a different nature, are as daunting as they were in the 1950's for the European continent. Tackling the energy issue is indeed surely a key factor to consider.

The Euratom Treaty created a sui generis Community with its own legal statute. The Community is made of, on one side, the signatory Member States and, on the other side, an independent Commission established by the Treaty. Each Member State has one Commissioner seat in the Commission but they have to act, collectively, in the interest of the Community and not of their own country. The Commission is mandated to ensure that the Member States fully respect the terms of the Treaty and has the sole right to propose further secondary legislative texts, within the scope of the Treaty. These texts, once approved by the Member States in the Council, become then an additional binding European law, the implementation of which again falls under the control of the Commission.

So, to make it simple, Member States have the full right to decide if they approve what the Commission proposes. But once approved they give the power to the Commission to control that they properly implement what they commonly decided.

The Euratom Treaty is a promotional Treaty, fostering the development and deployment of nuclear energy. It is made of several Chapters, covering diverse aspects of collaboration. It is not the place here to provide a full detailed analysis of the content of the Treaty, but instead to give a general understanding of what it covers:

- Fostering Innovation, Research and Development and creating the Joint Research Center JRC

  Innovation, Research and Development is central for the development and deployment of nuclear energy. Costs are high, even more when progressing towards higher technology readiness levels, requiring to recourse to expensive pilot and demonstration facilities of industrial nature. Pursuing these efforts in common, sharing manpower, facilities and budgets makes good sense, for the benefit of all participating countries. In the case of Euratom, one further step was taken by the establishment of a Joint Research Center, under the control of the Commission.
  Underneath this Chapter of the Euratom Treaty, the Euratom Research Framework Programme, managed by the Commission, provides budgetary means for joint research projects. Teams of experts from national laboratories and research centres, industry, and the Joint Research Center can apply for financing, by providing project proposals. The proposals are selected by the Commission, with the support of independent international experts.

- Dissemination of information and open collaboration

  Working together in full collaboration requires that information is openly disseminated among the Member States in the areas which are commonly agreed. Rules need to be established to ensure that this dissemination works well. In particular, the outcomes of the European research programmes are largely disseminated via large Conferences organised every two or three years. At the time Euratom was created, information was in paper form only… things are now completely different, bringing new opportunities and challenges.

- Health and Safety and Radiation Protection Standards

  In 1957, nuclear safety was not so developed as today. Priority was given to rules to protect the health of workers and population against radiation, which led to the establishment of the Basic Safety Standards (in fact common radiation protection norms). Since then, secondary legislation has been developed to cover particularly the safety of nuclear installations (Euratom Directives of 2009 and 2014 – this last one integrating the lessons of the Fukushima accident, including the lessons learned from the European Nuclear Safety Stress Tests). Under these Directives, while leaving the final responsibility for nuclear safety with operators and national safety authorities, the ENSREG (European Nuclear Safety Regulators Group) has been established, gathering the safety authorities of all the Member States and the Commission, to foster open and effective collaboration.
  One has also to mention here the Directive of 2011 on waste management, a topic not very high in priority in 1957, but which is now predominant for public acceptance of nuclear energy. This Directive fosters the timely research, development and implementation of waste management programmes and solutions, including geological disposal, by the Member States, under the control of the Commission.

- Programming, Investments and Joint Undertakings

  As mentioned, the Euratom Treaty is a promotional Treaty. The Commission is asked to issue on regular basis (every five to ten years), an indicative programme (non-binding) to foster the development and deployment of nuclear energy, for the benefit of the Community as a whole. The nickname of this programme is PINC (French acronym for Programme Indicatif Nucléaire de la Communauté). Once this is done, it gives indications for where investments should be made, either as the Community or at national level, by public and private stakeholders. And to foster some investments, the concept of Joint Undertaking JU was established, pulling together interested parties for one given main project, benefitting of some tax exemptions to make it appealing. This Joint Undertaking process has been used to build and operate some large pilot demonstration facilities. Member States are also required to provide detailed information on planned nuclear projects to the Commission. The Commission then issues an advice on the project and keep record and track of all nuclear projects in the Community

- .Fuel Supply and Euratom Supply Agency

  At the time the Euratom Treaty was signed, there was a fear that Uranium resources would be limited. To avoid undue competition among the Member States for the access to the resources, the Treaty created the Euratom Supply Agency, having the task to keep track of and co-sign all nuclear fuel contracts in the Community. Confidentiality rules apply on the content of the contracts, in particular on the financial aspects. The role of the Agency is helpful to ensure a good long-term security of supply of nuclear fuel in the Community.

- Safeguarding nuclear materials

  The Treaty also created, within the Commission, a pool of safeguards inspectors, in charge of safeguarding nuclear materials to avoid diversion of nuclear materials. Euratom Inspectors, officials of the Commission to ensure the full independence, are visiting all nuclear installations in the Community. The Joint Research Centre is providing technical support for the Euratom inspectors, and collaborate with the IAEA inspectors.

- Ownership, Property Rights, Markets

  Nuclear energy is a big business. The Treaty creates an open nuclear market for the Community. Rules needed to be defined to manage the ownership and property rights.

- External Relations

  Finally the Treaty defines a specific role for the Community when it comes to external relations, allowing the Commission to sign, for the Community, international agreements with third countries. This gives much more weight to such agreements as they engage the full European region (and its market) and not a single country. One or more Member States may be party to such agreements. Member States have also the right to sign international nuclear agreements on their own but they need to inform the Commission, who verifies that there is no incompatibility with the Treaty and the interests of the Community.

VIII. Lessons from the implementation of Euratom in an evolving European Union

The Euratom Treaty has been a useful tool to foster the development and deployment of nuclear energy at the early stages, in the 1960's and 1970's. It provided the basis for a dynamic collaborative Community. It helped streamline, organise and finance nuclear research for the benefit of all participating stakeholders. It also placed the Community in a forefront position among the main nuclear regions in the world. In the 1990s, it fostered the consolidated Community action to tackle the safety issues of Soviet designed reactors, some of which were in operation in eastern European countries (before they became Member States of the European Union). The nuclear TACIS (Technical Assistance to the Commonwealth of Independent States) programme spent more than 1 billion Euros over 20 years in projects improving nuclear safety. In 2011-2014, the Euratom Treaty helped the Community to provide an adequate response following the accident of Fukushima. This accident could have led to diverse and divergent responses in the Member States. In the days following the accident, the Commission quickly organised the discussion among the European nuclear stakeholders (Member States, Safety Authorities under ENSREG, and operators and industry) and proposed the setup of a wide peer review programme, called the "nuclear stress tests". With the support of the Joint Research Center, it allowed to review the level of resilience of each and every nuclear reactor in Europe, and to propose, if needed, adequate and timely measures to increase the strength of these reactors against external events.

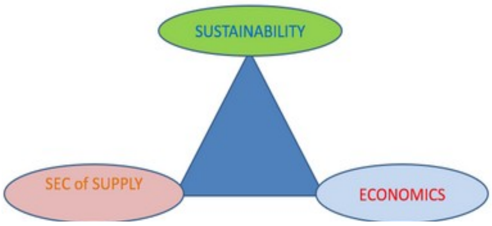
This being said, going from the initial six Member States to the actual 27, has brought major challenges to the dynamics of the Community, and in particular its promotional dimension. Indeed, the Community, under the Euratom Treaty, operates by consensus, meaning that unanimity is required to take decisions on proposals by the Commission.

Since the 1980s, the anti-nuclear movement has become more and more influential in the European Union. Originating from green NGOs initially, it entered the political arena. Today green political parties are active in most European countries and participate in governing coalitions. In most cases these parties have an anti-nuclear standpoint. This has led to a very diverse positioning of the Member States on the role that nuclear energy has to play. While the European Union wants to be a leader and a model in the fight against climate change, and while nuclear energy is quasi carbon free, some Member States have a declared anti-nuclear policy. This is against the promotional nature of the Euratom Treaty and blocks a number of initiatives which would have otherwise helped the Community to foster the further contribution of nuclear energy in the very low carbon energy mix of the future. In particular, most European financial instruments created to support large investments in technologies to reduce climate change are excluding nuclear energy projects.

The best and most recent example is the saga around the Taxonomy for Sustainable Financing. To promote investment in "sustainable" technologies, the European Union wanted to define a set of criteria helping investors and financing institutions to define what is sustainable and what is not. It took nearly four years and very harsh and politicised discussions to finally agree that nuclear energy can indeed be considered as sustainable, at least for the transition towards carbon neutrality in 2050. It can only be surprising to see how long it took, in a Community built on a Treaty which is promotional for nuclear energy development and deployment…

IX. The good definition of sustainability: environmental versus wider societal sustainability…

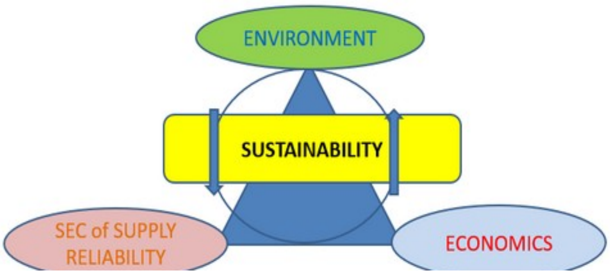
What is at stake is the too limited definition of sustainability used in the discussion at EU level. Sustainability is usually considered as one of the three pillars of energy policy as illustrated by the figure below (source: author, weCARE)[2], the others being economics and security of supply. The focus is solely on the impact on the environment (at large). Sustainability is equal to environment protection. This is much the result of decades long « green » lobbying. In short, green is equal to clean for the environment, and green is sustainable. What is not green is not sustainable. This is by far short-sighted.



A wider definition of sustainability is necessary, properly encompassing the three pillars all together. One should go back to the principles of the Brundtland's Report « Our Common Future" 1987 [3]. The original definition of Sustainable Development according to Brundtland was:

- [development that] meets the needs of the present without compromising the ability of future generations to meet their own needs
- but sustainable development requires meeting the basic needs of all and extending to all the opportunity to fulfil their aspirations for a better life (i.e. poverty eradication worldwide).

Underneath this principle, it would be wise to build the definition of societal/social sustainability of energy by referring to the three pillars of a sound energy policy: (i) environment protection, (ii) economics and affordability of energy, (iii) security and reliability of supply. Sustainability is the result of a balance between the three pillars, and these pillars are interacting with each other, as illustrated in the figure below (source: author, weCARE). It is worth noting that a similar re-definition of sustainability for nuclear fission was put forward by the European Union in 2013 in an Euratom Symposium, requested by the EU Council and co-organized by the European Commission and the European Economic and Social Committee, under the title "*Benefits and limitations of nuclear fission for a low-carbon economy*" (Brussels, February 2013)[4].



Energy is the necessary blood for development, it needs to be affordable for the economy and users (industry and households), reliable in order to be available when needed, and for sure be respectful of the environment. One might for sure strive to reduce the amount of energy needed to keep societies running properly. Energy efficiency is a major important endeavour to pursue proactively. Already over the last decades, a decoupling between the gross domestic product (GDP) and the energy consumption has been observed locally in developed countries, which is all good but looking at the demography worldwide and the legitimate hope for better access to energy for all, no doubt that the overall amount of energy consumed worldwide will further increase. And even in developed countries, where more will be done with less energy, the trend is to go towards more electrification (e.g. digitalisation, electric cars,…) to replace the use of fossil fuels, avoiding air pollution especially in large cities and targeting "an economy with net-zero greenhouse gas emissions" by 2050.

So, an energy source could be considered as sustainable if it complies with the three criteria of cleanliness, affordability and reliability. No single source of energy is perfect from all criteria perspective. It is a matter of balancing the pros and cons for each of the criteria and strive for a fair balance. For sure a lot will also depend on whom you talk to, or where people are putting their priority: green lobbies will focus on the environmental protection pillar, industry on the cost and reliability of supply of energy, households on the affordability… but one thing is sure, there is no silver bullet for now… will one appear in the future?… betting on it is a risk. It seems reasonable for now to keep all options open at a time when there are too much parameters and unknowns in the equation. The figure below illustrates the wider concept of sustainability for energy (source: author, weCARE – the name reflecting the logo: Clean Affordable Reliable Energy for societal sustainability).

In fact, one should go even further: applying the triangle of the three pillars to compare the diverse sources of energy between them is not enough. What needs to be done is to use the triangle to judge the societal/social sustainability of the global energy system, by integrating the interactions between the diverse sources constituting the system. This is particularly true for electricity where the diverse forms of production are linked through the grid and the market, and are influencing each other. The impact of this linkage can be very important where the market is badly designed or where its functioning is biased by artificial policy driven measures, such as subsidies and other support methods.

The sustainability of the whole system should first be analyzed based on a level playing technology neutral field, where each source is considered as objectively as possible versus the three pillars, without a priori exclusion, and policy making decision on the energy mix made only afterwards. What we observe mostly is the inverse: policy choices of energy sources are made upfront without proper analysis of the sustainability of the whole system, distorting the picture and making a proper analysis and decision making impossible.

To illustrate this, one may consider the cost of the intermittency of renewable energy sources (photovoltaics and wind). Decisions have been made, in a number of countries, to massively support their deployment because they are clean for the environment as the sole criteria. The policy driven initial deployment, paid by the electricity consumer and the taxpayers, is claimed to have allowed a strong reduction in the cost of the electricity produced by windmills and solar panels, soon reaching grid parity, meaning justifying furthe rinvestments on an economic, market based, principle. But the cost talked about here is the LCOE (Levelized Cost of Electricity) at the output of the windmill or solar panel. It does not reflect the costs of the electricity to be produced by other means when there is no wind or sun (noting a windmill has a "load factor equivalent at full capacity" of the order of 25% for onshore and 40% for offshore, and a solar panel

15% - average figures for Europe). From a global energy system perspective, it would be more logic, to have a first sense of realities, to « compare » the cost of the electricity produced by a very low carbon nuclear power plant producing 85% of the time (the average load factor for nuclear plants), with the cost of an intermittent renewable source multiplied by the ratio of the nuclear load factor divided by the load factor equivalent of this renewable source[5]. As an alternative, one might furthermore add to the LCOE of the windmill or solar panel, the cost of producing electricity by a "dispatchable source", e.g. a biofuel plant or an "electricity storage" facility coupled with the renewable source to compensate for the intermittency during the time there is no wind or sun, so as to reach a global load a factor equivalent of 85 %. And this calculation does not integrate the expected lifetimes of the installations (60 years for a nuclear plant, 20 or 25 years for a windmill or a solar panel).

X. CONCLUSION

Euratom, as a Community of Member States under the heading of the Euratom Treaty, has been conducive to the effective development and deployment of nuclear energy in the European Union over the last 60 years. Signed in the aftermath of the WWII to rebuild the continent, it fostered cooperation going well beyond intergovernmental agreements. In recent years, the promotional dimension of the Treaty has been weakened by the anti-nuclear policies of some Member States, much influenced by the "green" movement. The future will tell us if the recent events in Ukraine and their impact on the security of supply of energy in the European Union change that trend.

At a time when the world is facing major challenges, from climate change to resource scarcity, demography and increasing energy needs, African countries might consider the pros and cons of the Euratom experience, to design, themselves but together, their sui generis "African Atomic Energy Community". Nuclear energy being clean, hyper concentrated, available and safe if properly managed, it is worth to consider its inclusion in the energy mix of Africa in the future, and to design the most appropriate way for Africa to benefit from it… nuclear energy for Africa by Africa might be the moto for Africatom.

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Fault identification in Distribution transformers: Case of Fako Division, Cameroon

Wirnkar Basil Nsanyuy
Faculty of Engineering and Technology
University of Buea
Buea, Cameroon
wirnkar.basil@ubuea.cm

Nde Donatus Nguti
Faculty of Engineering and Technology
University of Buea
City, Cameroon
nde.nguti@ubuea.cm

Emmanuel Tanyi
Faculty of Engineering and Technology
University of Buea
City, Cameroon
emmantanyi@gmail.com

***Abstract*—In this study, the causes of frequent failures in distribution Transformers in Fako Division of the Southern Interconnected grid (SIG) of Cameroon have been investigated. The aim of the study is to bring out the common causes of distribution transformer failure in this area. The study revealed a failure rate of about 18% resulting mainly from over loading. The loading situation showed that over 75% of distribution transformers were operating in unbalanced mode while an estimated 20% were overloaded. Therefore, acting to predict this situation would be done with WSNS and this will save the transformers from failing.**

***Keywords*—Transformer faults, Wireless sensors, unbalancedmode, load growth, Cameroon.**

XI. Introduction

The power company would be unable to supply electricity to end users without a distribution transformer. The transformer uses electromagnetic induction to transmit energy between two or more circuits. A distribution transformer failure is a disastrous and costly event because it causes a power outage in the transformer's service region. Distribution transformers are used for more than sixty years [1, 2]. Many distribution transformers have failed in recent years, even after only a few years of service. As a result, numerous investigations have been conducted to determine the primary causes of distribution transformer early failure. As per a research carried by C.Ndungu et al [3] in Kenya, the annual failure rate is above 10%-12%, much greater than the 1-2% failure rate in affluent countries (as per Kenya Power documented incidents of faulty transformers). Ayalsew Tariku and Getachew Bekele [4] conducted an inquiry and discovered that eighty-nine transformers had burned down in just one year. Located in one of the four regions in Ethiopia's capital, Addis Ababa. The reasons are numerous, with the leading causes accounting for approximately 85% of the total. Overloading, load unbalances, and protection device ratings are all factors to consider as well as lighting, improper operation and maintenance, as well as a lack of testing and diagnosis resources, as well as a dearth of competent labor to carry out repairs and maintenance. It has been noted that while distribution transformers are relatively inexpensive (in comparison to power transformers), utilities put little effort into determining the fundamental cause of transformer failure. One of the reasons why more failures occur immediately or within a short period of time after replacing a damaged transformer could be due to a lack of root cause investigation [5, 6, 7]. Electrical, mechanical, and thermal factors all have a role in transformer failure owing to insulation breakdown, according to study conducted by William H.B of Hartford Steam Boiler (2005) [6]. Operation of the transformer under transients or sustained over voltage conditions, exposure to lightning surges and switching surges, or partial discharge (corona) due to inadequate insulation system design are all electrically induced factors. Mechanically induced factors, on the other hand, include looping of the innermost windings, conductor tilting, conductor telescoping, and coil clamping system failure. Deterioration of cellulose insulation of oil and insulation material of the windings are examples of thermally induced causes. Thermal induced factors are primarily caused by overloading beyond the transformer's design capacity as a result of cold load pickup (loads transformer supplies after restoring power after a long power outage), failure of the transformer cooling system, operating the transformer in an over excited condition (under frequency), and operating under extreme ambient temperatures [8, 9]. According to researchers [9], there are a number of things that can be done to extend the life and efficiency of distribution transformers (The expected life span of transformer above 100KVA is 35 years while below 100KVA is approximately 25 years) ; appropriate and good design are examples of these measures. In recent years, transformer manufacturers have compromised on both quality and reliability. This is accomplished through a lack of appropriate clearance for unrestricted air circulation, the use of a small winding wire that cannot handle increased current densities due to short circuit situations, and the incorrect use of inter-layer materials. Enhanced O&M to ensure that the transformer's oil level is sufficient, as well as clearing trees that are a common source of high impedance faults, proper fuse grading, and the removal of condensed water from the transformer. Some of the measures utilities must take to avoid early failure of distribution transformers include using the correct diversity factor to avoid overloading the transformer and avoiding two phasing in rural areas, which causes unbalanced current and raises the potential of neutral with respect to the earth. The majority of transformers of industrial and institutional customers are prematurely failing. According to study conducted by R. Singh et al (2014) [8], a growth in nonlinear loads in both sectors and institutions has resulted in high harmonic content, which increases current and leads to transformer over-load. It's worth mentioning that the level of harmonic frequencies present has a direct relationship with winding copper losses (I2R), core losses, and stray losses, all of which raise the operating temperature of a transformer significantly. It's worth noting that the average transformer life is directly related to the average life of the insulating materials. Harmonics and frequency changes in a steady-state power supply are the principal causes that hasten the aging of insulation materials and, as a result, the early failure of distribution transformers [10, 11, 12, 13]. There is little or no research reports on Cameroon at large and Fako in particular, as a result, a research was conducted to determine the main causes of distribution transformer failure in the Fako Division.

XII. Methodology

ENEO (Energy of Cameroon) is the main distributor of energy in Cameroon in general. The energy infrastructure is divided in Cameroon into 3 main subnetworks namely; the Northern Interconnected Network(NIN), the Southern Interconnected Network(SIG) and the Eastern network. Fako division is a sub area in the SIG and is further divided into 6 administrative units(subdivision) including Buea, Muyuka, Tiko, Limbe I, Limbe II and Limbe III. All the 6 areas are supplied by the same substation at Mile 2 Limbe with a Power transformer of 50MVA 90kV/30kV. The Fako area has 560 distribution transformers of power rating 25kVA, 50kVA, 100kVA, 160kVA, 250kVA, 300kVA,4 00kVA, 500kVA and 630kVA. Table 1 displays the number of transformers that failed from January 2019 to July 2021, as well as the probable cause of failure while table two on the other hand shows the loading situation of the transformers in this area. The number of transformers installed per sub area is represented on table 3.

TABLE VIII. Total number of failed transformer per area and suspected causes

Causes	**Buea /160**	**Muyuka/73**	**Tiko/65**	**Limbe I/62**	**Limbe II/98**	**Limbe III/102**	**Totals**
Lightning	0	0	0	0	0	0	0
Vandalism	2	3	2	0	0	0	7
Fault on LV System	0	0	2	1	1	3	7
Broken Bushings	0	0	0	0	0	0	0
Burnt/ Broken Rods	0	0	0	0	0	0	0
Oil Leakage	0	0	0	0	0	0	0
Accidental Damage	0	0	1	0	0	0	1
Overloaad	22	12	13	11	16	17	89
Internal Defects	0	0	0	0	0	0	0
	24	15	18	12	17	20	106

TABLE IX. Loading situation per area

S/N	Area	Installed	Overloaded	Unbalanced
1	Buea	160	34	130
2	Muyuka	73	15	65
3	Tiko	65	12	58
4	Limbe I	62	13	55
5	Limbe II	98	20	82
5	Limbe III	102	25	93
	Total	560	119	480

TABLE X. Transformers per area

S/N	Area	Installed	Overloaded	Unbalanced
1	Buea	160	34	130
2	Muyuka	73	15	65
3	Tiko	65	12	58
4	Limbe I	62	13	55
5	Limbe II	98	20	82
5	Limbe III	102	25	93
	Total	560	119	480

XIII. Causes of frequent failures of distribution transformers

The following are some of the reasons for distribution transformer failure that can be traced back to the utility. To lower the rate of failure, possible remedial measures have been indicated.

A. Overloading

Overcrowding is seen in urban areas as a result of rising population, and in rural regions as a result of rising irrigation pump sets and uncontrolled loads.

Continuous overloading of Distribution Transformers is not recommended since it compromises the winding insulation strength, resulting in failure.

B. Improper LT and HT protection

When transformer fuses are often blown, maintenance personnel replace the fuse element with a higher rating to minimize frequent power outages and fuse replacement. This is due to a shortage of skilled workers who are constantly overworked. The management team is also overworked! The solution is to hire a sufficient number of skilled employees and supervisors. The use of a Tong Tester to measure load current at numerous intervals, especially during peak loading hours, will provide a good indication of the locality's load demandthe extra authors. If the overloading is greater than 20% during peak hours and lasts for several days, it is recommended that the existing transformer be replaced with one of higher rating, or that a second unit be added in parallel.

C. Single phase loading

A balanced load should be linked to a distribution transformer. However, in rural regions, running irrigation pumpsets with phase conversion overloads the transformers, causing them to fail. The primary motivation for the aforementioned act is a lack of power. Regular monitoring is one of the immediate remedies.

D. Unbalanced loading

The load on each phase of a transformer is rarely checked by the maintenance or supervision team. The new connections are also distributed at random, resulting in greater unbalance and, as a result, neutral shifting. A circulating current will flow through the deltawinding loop because the neutral is strongly earthed through the external link. This additional circulating current will superimpose on the delta winding's main branch current, causing more heat and perhaps causing the winding insulation to break. The reality is that there is a staffing shortfall. The solution is to hire the necessary number of people and teach them to keep the neutral current to less than 10% of the total current.

E. Usage of repaired transformers

A transformer can break because of a small flaw, it can then often be fixed quickly, even in the field. This is a cost-effective method of reactivating the transformer. Due to a lack of funds, each distribution transformer is fixed 2 to 3 times over its 25-year life lifetime, lowering the efficiency even more with each repair. The cost of repair or replacement is the direct economic impact of distribution transformer failure, but the indirect economic impact is revenue loss owing to supply interruption and higher current losses.

F. Power theft and hooking of mains

This frequently happens in order to power special events. As a result of such “uninvited” connections, the transformers will operate at an overload/unbalanced load, which may result in failure over time. This is one of the most common reasons of distribution transformer failure, for which the authors are always held accountable. Regular monitoring, rigorous actions against theft cases, energy audits, initiating stringent actions, and other measures can be implemented to reduce this.

XIV. Results and discussion

From Table 1, faults emanating from overloading (resulting from unbalanced loading, energy theft, poor workmanship etc) were suspected to be the main cause of premature failure of distribution transformer accounting for (83.9%). Vandalism and Fault on LV System and others constitute minor causes. From table two, an estimated 119 (21.25%) of the 560 transformers installed are running on overload (>80% loading) while about 480 are loaded unbalanced (85.7%), showing that most transformers are likely to fail in the near future resulting from the latter. Due to a high impedance fault (which could be produced by a tree branch hitting a phase) or cold load pickup, the transformer was overloaded for an extended period of time due to unbalanced transformer loading. The high current causes thermal heating (losses) in the transformer, which raises the temperature of the windings and insulating oil, shortening the transformer's life. Heat speeds up the aging of oil cellulose, lowering the degree of polymerization (DP) of solid insulation, which offers dielectric and mechanical isolation for the windings [8]. The other causes may not be suspected to have caused any failure but we cannot overlook them as future potential causes of failures.

XV. Conclusions and recommendations

The following conclusions were drawn from the research;

1) It was discovered that the failure rate of distribution transformers in the Fako division is increasing, and that this trend must be reversed. Currently, the failure rate is 19 percent, compared to an annual failure rate of 1-2 percent as indicated by international standards
2) Vandalism of the transformer's earthing system, both on the HT and LV sides, exposes the transformers to high voltage surges, which cause insulation breakdown and early transformer failure.
3) The majority of distribution transformers appear to be changed without technical professionals determining the root cause of the problem. The rate of transformer failure has risen as a result of this.
4) Transformer overload is caused by high harmonic current, particularly triplen harmonics (which circulate within delta windings), triggering HV winding insulation degradation
5) Over 85% of installed transformers run on unbalance loading resulting from random connections and power theft.

The authors advise the power company ENEO to adopt the following steps to extend the expected service life and efficiency of distribution transformers

1) By properly grading the LV fuses, you may avoid transformer overload. The use of direct links should be avoided at all costs. Fuse boxes for each circuit should be separate. There will be no sharing of fuses to control multiple circuits
2) By using the suitable fuse rating and earthed LAs, the transformer will be fully protected. When a fault develops along the feeder, 76 percent of distribution transformers have no expulsion HT fuses, exposing the transformer HV windings to large fault currents
3) Wireless Sensor Networks should be installed to provide the power infrastructure with real-time monitoring.

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ABSTRACTS of contributions without related full paper available in these proceedings

Moroccan Energy Strategy

Prof. Rajaâ Cherkaoui El Moursli,

Resident Member of the Hassan II Academy of Science and Technology,
Member of TWAS, Fellow of the African Academy of Sciences

Morocco is a country facing the virtual absence of identified fossil energy resources (hydrocarbons, coal) and a heavy dependence on imports, which until 2018 covered more than 90% of national energy needs. Morocco is actively trying to remedy and change this situation.

Morocco's commitment to an energy transition is a proactive political choice made by His Majesty King Mohammed VI, more than a decade ago, through an ambitious energy strategy, based essentially on the rise of renewable energies, the development of energy efficiency and the strengthening of regional integration, accompanied by a strong orientation of adapted innovation and local control. Main Orientations aims to raise the Kingdom's ambitions to exceed the share of renewable energies in the energy mix to more than 52 % in 2030.

This vision has already started to give results. About 48 Renewable energy projects with a total installed capacity of about 4 Gigawatts are already in operation. In addition, more than 50 other projects are under development or implementation. These projects have strongly contributed to electricity production and to the reduction of energy dependence by 8 points since 2009.

It is important to note that Moroccan renewable energy projects are made possible thanks to the establishment of an appropriate legislative, regulatory and institutional framework. This framework is updated regularly to improve the business climate and make the renewable energy sector more attractive to private investment.

Research, development, innovation and industrialization in the fields of renewable energies and energy efficiency are an essential pillar for the success of our energy transition. It was proceeded, first of all, with the creation of an institution dedicated to R&D&I in the field of green energies, notably the Research Institute for Solar Energy and New Energies, for the financial support of innovative research projects with the involvement of industrialists, and then the development of new research platforms at the service of innovation and researchers.

A new strategic vision to 2030 for R&D an innovation in the field of green technologies has been adopted, aiming in particular to further strengthen Morocco's role at the regional and international level in terms of energy transition.

Local industrial integration is also an objective of Moroccan energy model. On this subject, three photovoltaic module factories with 300 Megawatts per year and a wind turbine blade factory with an annual capacity of 1000 MW have been set up.

New initiatives have been launched in these recent years to accelerate the Moroccan energy and the economic transition towards a low-carbon model and to meet the socio-economic needs of the population.

International cooperation in research and innovation is a strategic priority for the EU,

Fadila Boughanemi

Deputy Head of Unit H2: Asia, Africa, MENA and External Relations, DG Research and Innovation · European Commission

International cooperation in research and innovation is a strategic priority for the EU. It enables:

- access to the latest knowledge and the best talent worldwide
- business opportunities in new and emerging markets
- science diplomacy to influence and enhance external policy

Multilateral research and innovation initiatives are the most effective way to tackle challenges facing our world - climate, health, food, energy and water - that are global by nature. Working together reduces the global burden, pools resources and achieves greater impact.

The European Commission leads many global research partnerships. These partnerships are important for the EU to meet its international commitments like the Sustainable Development Goals (SDGs).

Fadila Boughanemi will present an overview of the renewed EU Global Strategy for Research, Innovation, Education and Youth, to be adopted by spring, with a specific focus on Africa.

Fadila will highlight the scientific priorities with the continent, and the future perspectives of cooperation in R&I.

Renewable Energy as an enabler for socio-economic development in Africa

Nopenyo Dabla

Programme Officer in charge of Sub-Saharan Africa at the International Renewable Energy Agency (IRENA),

Endowed with substantial renewable energy resources, Africa is in a position to adopt innovative, sustainable technologies and to play a leading role in global action to shape a sustainable energy future. Supply unreliability is a concern holding back economic development, with most countries facing frequent blackouts and often relying on expensive and polluting solutions. Clean, indigenous and affordable renewable energy solutions offer the continent the chance to achieve its economic, social, environmental and climate objectives. Sustainable development and use of the continent's massive biomass, geothermal, hydropower, solar and wind power have the potential to rapidly change Sub-Saharan Africa's current realities and offer the continent the chance to achieve its economic, social, environmental and climate objectives.

IIndeed, Africa could meet nearly a quarter of its energy needs from indigenous and clean renewable energy by 2030. Modern renewables amounting to 310 gigawatts (GW) could provide half the continent's total electricity generation capacity. This corresponds to a sevenfold increase from the capacity available in 2017, which amounted to 42 GW. A transformation of this scale in Africa's energy sector would require average annual investment of 70 billion US dollars (USD) to 2030, resulting in carbon-dioxide emissions reductions of up to 310 megatonnes per annum (IRENA, 2015).

Data shows that at least 25 African countries have electricity access rates of less than 40 per cent. Access to clean cooking is still one of the significant challenges, as these countries consistently rely on biomass fuels and technologies for their thermal needs. Additionally, the region's growing population and economic progress call for a rapid increase in supply on the continent, to which renewable energy must contribute in the decades ahead. Africa therefore has a unique opportunity to pursue sustainable energy development as a basis for long-term prosperity. Tackling today's energy challenge on the continent and preparing for tomorrow's needs, therefore, requires a firm commitment to the accelerated use of modern renewable energy sources.

In this context, through partnerships at continental, sub-regional and national levels, the International Renewable Energy Agency (IRENA) has been supporting Sub-Saharan African countries in their transition to a sustainable energy future in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. More specifically, this support spans across the implementation of the Clean Energy Corridor initiative in Eastern, Southern and West Africa; as well as the regional engagement in Central Africa, and under the access thematic, covering entrepreneurship support and the electrification on rural health facilities. IRENA support is also geared towards supporting countries in the enhancement and implementation of their climate change ambitions.

The objective of this proposed presentation would be to reflect on the role of the energy transformation in order to achieve sustainable development and climate objectives.

Les business models de la transition énergétique en Afrique de l'Ouest(CEDEAO)

Faustin DAHITO,

Groupe ENERDAS
et AISER-Bénin (Association Interprofessionnelle
des Spécialistes des Energies Renouvelables)

La situation énergétique des Etats de la CEDEAO est caractérisée par un faible taux d'électrification (environ 35 % dans le secteur urbain et 8 % dans les zones rurales).

Les réseaux électriques de transport de l'électricité affichent des pertes en ligne de plus de 20 %. La biomasse est la forme d'énergie la plus utilisée par les populations, ce qui favorise du coup la dégradation des forêts et contribue à l'accélération du changement climatique.

L'électricité est une ressource vitale pour la prospérité économique des nations. Les pesanteurs qui minent les performances économiques des Etats de la région sont notamment engendrées par la faible disponibilité de l'énergie électrique par tête d'habitant qui est de l'ordre de 0,6 tep dans la CEDEAO contre 20 tep en Europe et 30 tep en Amérique du Nord. Triste réalité linéaire avec le produit intérieur brute par tête d'habitant.

Conscient de l'importance des enjeux, la CEDEAO a décrété une ambitieuse politique de développement des énergies renouvelables pour endiguer la pauvreté énergétique des Etats et limiter les maux qui freinent la prospérité économique des Etats.

Les directives majeures sur les économies d'énergie et d'efficacité énergétique consolident la politique de développement durable dans les Etats qui ont tous adopté dans leur programme d'action gouvernementale une politique de développement des énergies renouvelables orientés vers l'utilisation de l'énergie solaire photovoltaïque ou thermique, de la biomasse, des éoliennes et de l'hydroélectricité.

Sur le plan législatif et règlementaire, les codes nationaux de l'électricité ont évolué dans un nouveau paradigme de diversification des filières énergétiques. La démonopolisation du marché de l'électricité, a ouvert la voie à l'investissement privé dans tous les Etats. Le mixage responsable de l'électricité des réseaux conventionnels devient la mode du jour accélérant ainsi la densification des capacités nationales de production, la résilience des réseaux électriques face aux aléas du changement climatique.

La nouvelle dynamique en cours a impulsé des initiatives nouvelles. La densification des réseaux électriques ainsi que les capacités de production nationale s'accélèrent dans l'ensemble des Etats des régions. Le développement de la recherche scientifique et appliquée se nourrit également de la formation des cadres experts formés aux sciences et technologies des énergies renouvelables.

Les politiques d'économie d'énergie appellent les stratégies nationales d'efficacité énergétique. De nouveaux Business Models émergent en conséquence, orientés vers le développement des projets en partenariat public privé ainsi que des contrats de performance énergétiques.

Avec le soutien des partenaires techniques et financiers aux Etats, le mouvement de la transition énergétique est en pleine marche dans la région CEDEAO, accélérant le renforcement des capacités des acteurs sectoriels et le développement des nouvelles filières professionnelles. Grâce à la coopération internationale, des joint-ventures et autres alliances stratégiques se créent entre les firmes internationales et les entreprises locales.

Les énergies renouvelables constituent la voie d'avenir du développement durable des nations d'Afrique et du Monde. L'immensité du gisement solaire permet d'augurer des résultats positifs pour l'avenir énergétique de la région.

Institut de Recherche en Energie Solaire et Energies Nouvelles (IRESEN) : three new research and innovation platforms in Morocco (the Green & Smart Building Park ; the Green H2A ; the Green Energy Park)

Badr IKKEN,
Directeur général de l´Institut de Recherche en Energie Solaire et Energies Nouvelles (IRESEN)

"Between 2016 and 2030, the primary energy demand of Morocco will be nearly tripled and quadrupled for electric power. Morocco has a vision to clear the way to becoming a major player in renewable energy, especially solar energy. It is planned to deploy more than 10000 MW of renewable energy across the kingdom in the next 10 years. The share of renewable electricity will be 52%, which will outweigh the share of fossil fuel electricity. To support the national energy strategy, several active institutions were created under the trusteeship of the Moroccan Ministry of Energy, Mines and Sustainable Development: MASEN - The Moroccan Agency for Sustainable Energies, AMEE - The Moroccan Agency for Energy Efficiency, SIE - The Energy Investment Company and IRESEN - The Research Institute for Solar and New Energies. IRESEN has been set up in 2011 by the Ministry of Energy, Mining, and sustainable development, with the participation of the key players of the energy sector in Morocco.

To reach our ambitious target, it was important to have a long term strategy and to develop adapted ecosystems to meet the needs and challenges. The technology adoption is playing an important role. Research and Innovation is fostering the energy transition by addressing optimally energy needs in Morocco while including economic development through local manufacturing of new products and offering specific new services.

IRESEN as an applied research catalyst in renewable energies is facilitating and coordinating the setting up of adapted R&D infrastructure, projects as well as national and international partnerships propitious to knowledge acquisition and innovation. To reach these fixed objectives, a strategy founded on two pillars was elaborated and sat in place:

- • bring the university closer to the industry by means of financial support to a high quality applied R&D projects submitted under the framework of a well oriented and focalized call for proposals. Today more than 800 researchers and Phd students are supported by IRESEN to conduct innovative projects in several fields, like adapted solar and wind technologies, use of renewable technologies in industrial applications, water treatment, city and mobility of the future...
- •set up the conducive infrastructure and laboratories for R&D jointly with the national universities to create the complementary scientific platforms of excellencies needed in different regions in Morocco while assuring an efficiency and mutuality of resources and respecting the demand/offer approach. To reinforce innovation across Morocco in the field of renewable energy and to promote human resources development, IRESEN developed and set up the first applied research and innovation network in the African continent. It is built around regional platforms for test, research and training in the field of renewables. This territorial network is set around universities and education institutions while developing technology know how transfer mechanisms to local industries. It addresses strategic needs and challenges in relation to energy to position Morocco as a gamechanger in innovation in the field of renewable energies and sustainable development. In addition to the medium and long term scientific vision, the Network will enable the local industry, in close collaboration with academia, to seize market opportunities in a very short term while complying with the so-called innovation criteria: scientific excellence, entrepreneurial skills, robust business model and strong networking.

The genesis of this Network was marked by the creation of the Green Energy Park (GEP), the international platform for test, research and training for solar energy. The “Green Energy Park”, a unique test, research and training platform in Africa has been established by IRESEN and the Polytechnic University Mohammed VI in Ben Guerir. It is covering the entire R&D value chain from basic research until proof of concept in the field of solar energy. Built on an area of 8 hectares, the GEP has an internal research platform, which includes several labs with cutting-edge technologies in the field of solar photovoltaic and thermal energies. Topics such as treatment and desalination of water using solar energy, development of desert modules, design of innovative thermal and electrical storage solutions and development of industrial applications of solar thermal energy are considered as major concerns of the Green Energy Park. The distinctive character of the GEP lies in the fact that the platform includes full size outdoor test platforms, which is a critically important factor for testing and validating solar components and technologies in real conditions. Different solutions regarding technology improvements, in design and in materials for hot Moroccan regions are developed and can be implemented in different regions in Africa.

Today three new research and innovation platforms are under construction, the Green & Smart Building Park, addressing the African city of the future, the Green H2A dedicated to power fuels as well as the first platform outside Morocco, the Green Energy Park MCI (Morocco Ivory Coast). The infrastructures will be also expanded to cover the nexus Water energy and the agro-energy. The aim of the this green continental research & Innovation network is to support and accompany the emergence of a green economy in Africa through a strong linkage between academia and industry. “

Exploring the first large-scale hydrogen, ammonia and fuel cell related activities and projects underway in Africa.

Bart Biebuyck

Executive Director of the
Fuel Cells and Hydrogen Joint Undertaking
(FCH JU)

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a public-private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realizing their potential as an instrument in achieving a carbon-clean energy system.

Hydrogen is an essential component in Europe’s energy transition. By 2050, it could account for 24% of final energy demand and 5.4 million jobs, according to a FCH JU roadmap report.

Fuel cells, as an efficient conversion technology, and hydrogen, as a clean energy carrier, have great potential to help fight carbon dioxide emissions, to reduce dependence on hydrocarbons and to contribute to economic growth. The objective of the FCH JU is to bring the benefits of this technology to European citizens through a concentrated effort from all sectors.

Fuel cell and hydrogen technology has made significant progress in Europe thanks to forward-thinking policy and targeted funding by the EU and industry. The three members of the FCH JU are the European Commission, fuel cell and hydrogen industries represented by Hydrogen Europe, and the research community represented by Hydrogen Europe Research. Collaboration between European researchers, industry and policymakers in a well-coordinated partnership delivers the most innovative and tangible results, boosting society's transition to a greener and cleaner world.

Growth of solar energy industry and opportunities

Prem Jain,
UNESCO Chair in Renewable Energy and Environment,
Department of Physics, University of Zambia (Lusaka)

This talk is an overview of a grand transformation which is taking place on our Earth with renewable energy rapidly replacing the use of fossil fuels. Since the 18th century, fossil fuels (petroleum, coal and gas) have fueled our industrialization and economies by providing cheap and convenient sources of energy. But they have now become a curse for humanity by being the cause of climate change. Burning of fossil fuels results in increasing greenhouse gases into the atmosphere. This is causing global warming by altering the natural radiative balance of the Earth-atmosphere system. Global warming is leading to climate change with adverse impacts on almost all sectors of human activity. Increased adoption of clean renewable sources of energy in place of fossil fuels has emerged as the way to mitigate climate change.

Solar energy is a leading source of renewable energy. Africa in general is endowed with plenty of this resource and is well-suited for its applications. Its use through photovoltaics was prohibitively expensive some decades ago but increased research and development have made it cost competitive. As a result, it is rapidly taking over from fossil fuels. An overview of the uptake of solar energy at global, African and Zambian level is given. Zambia is rapidly embracing solar energy. Four large programs have been set up recently – the IFC/IDC Scaling Solar, German-funded GET-FiT program, European Union - funded Increased Access to Energy and Renewable Energy Production (IAEREP) program and the Swedish funded Beyond the Grid Fund for Zambia (BGFZ). Opportunities for research, development and capacity building in solar energy are emerging. There is need for African universities to develop out-of-box thinking and bring relevance to their work by addressing the needs of their nations. In this connection, the role of the recently launched Solar Energy Centre (SEC) at the University of Zambia in providing critical support services to the emerging national solar energy industry is highlighted.

Role of Geothermal in Renewable Energy Mix

Atef Marzouk,
Ag. Director for Infrastructure and Energy
African Union Commission

Energy access is the main challenge for Africa and is a high priority at the AU agenda 2063. Currently, over 640 million Africans have no access to electricity, and an estimated 600,000 Africans, mostly women and children, die annually due to indoor air pollution associated with the use of fuel wood for cooking. The paradox is that there are huge energy resources in Africa, both in terms of renewable and non-renewable energy sources , including a potential of over 20 Gigawatts of geothermal resources in East Africa Rift Countries.

Geothermal energy has several attractive properties

- It is a carbon free dispatchable alternative to conventional energy systems.

- It is suitable for both centralised and decentralised power generation.
- It can be used for electricity generation, heating, cooling, green houses, etc.
- Technological progress increases accessible resources and drives down the costs.

11 African countries, namely: Burundi, Comoros, Eritrea, Ethiopia, Djibouti, Kenya, the Democratic Republic of Congo, Rwanda, Tanzania, Uganda, and Zambia called on the African Union Commission to play a role in harmonizing and coordinating the exploration and development of geothermal energy along the East African rift. These countries signed the Addis Ababa Declaration on Geothermal Energy in June 2009, giving birth to the Geothermal Risk Mitigation Fund, commonly known as GRMF. In 2020, Somalia became the 12th GRMF eligible country. GRMF, with a total budget of USD115 million, was created with the support of the German Federal Ministry for Economic Cooperation and Development (BMZ), the EU-Africa Trust Fund for infrastructure (ITF), through KfW and the UK Fund for International Development (DFID).

The overall objective is to encourage innovative financing, by providing grants for partial financing of 3 types of activities: (1) 80% of eligible costs for surface studies; (ii) 40% of eligible costs for drilling exploration wells and testing of reservoirs and (iii) 20% for the infrastructure upgrade (road access, electricity and water supply).

Since the launch of GRMF in 2012, grants totalling over US$ 117 million have been awarded to 30 projects with a potential of 2,800 MW, for a planned investment volume estimated to USD 9.2 billion.

However, several challenges and gaps still remain, among others: (a) inadequate policy, regulatory and institutional frameworks; (b) low levels of financing; (c) low levels of technical skills; and (d) weak geothermal information and databases.

Where policies and institutions exist, weak implementation of policies and regulations, result in uncoordinated markets and inefficient procedures.

Incentives must be increased for private sector participation: tax incentives, Feed-in-Tariffs (FiTs), and Power Purchase Agreements (PPAs), etc.

Besides, Africa is severely affected by the low levels of technical capacity and skills to build and maintain infrastructures that will enable effective operation of geothermal energy systems. The operationalization of the African Geothermal Center of Excellence since May 2018 helps training the African workforce to fill this gap.

he African Union Commission is firmly committed to support and accompany the development of geothermal resources in East Africa and encourages its bilateral and multilateral partners as well as International Financial Institutions to invest both technically and financially in geothermal resources in East Africa which still remains untapped.

Enjeux et perspectives de l’industrie de l’électricité en République démocratique du Congo… En attendant Inga 3 et Grand Inga

Fabrice Lusinde wa Lusangi Kabemba,
Directeur Général Adjoint de la Société Nationale d’Electricité,
SNEL SA en RDC

La situation énergétique de la République démocratique du Congo (RDC) est caractérisée entre autres par une prédominance de la biomasse énergie (bois-énergie représente 90% des approvisionnements nets d’énergie), une dépendance accrue aux importations d’électricité (10% de la consommation totale d’électricité en 2020) et une importante fracture énergétique entre la mégapole de Kinshasa, les villes et centres urbains, les provinces minières et les provinces agricoles-forestières.

Malgré une production de plus de 12 TWh en 2020, la RDC est un importateur net d’électricité ! En 2030, la RDC pourrait ne pas atteindre l’ODD no 7 et 84 millions de congolais vivront toujours sans accès à des services énergétiques modernes.

Ainsi, face à cette réalité, le Gouvernement a libéralisé le secteur en 2014 et entend ainsi : (i) garantir l’accès à l’énergie électrique à tous les congolais, (ii) améliorer le taux d’accès de l’électricité pour favoriser une industrialisation qui se veut verte et (iii) faire de la RDC une puissance énergétique à l’ère de la ZLECAF. Depuis 1923, l’industrie de l’électricité en RDC exploite seulement 2-3% de ses ressources énergétiques (EnR) estimées à plus de 170 GW : son gisement solaire 70 GW, ses ressources géothermiques et gazières et ses ressources hydroélectriques 100 GW (60 GW répartis à travers plus de 700 sites disséminés dans tout le pays + 40 GW site de Inga) et le développement possible d’une filière hydrogène-énergie.

Les actions stratégiques en cours d’ici 2030 concernent notamment : l’ouverture du marché de l’électricité et l’électrification hors réseau, l’éfficacité énergétique, les mesures et réformes institutionnelles (ARE, ANSER), réglementaires (Code de l’électricité), économiques, fiscales et tarifaires. La stratégie devrait s’appuyer sur des mécanismes de financement innovants et des solutions concrètes pour lever les obstacles aux investissements privés et les freins à la mobilisation et l'apport en capitaux (risques pays élevé), à travers des solutions techniquesadaptées à un contexte complexe et d'une grande fragilité. Chaque plan (comptage, stockage, solaire, hydro ou hydrogène) doit reposer sur un business model qui prend en compte : (i) le faible pouvoir d'achat qui peut rendre la demande imprévisible, (ii) l'absence d'infrastructures et voies de communication pour acheminer les équipements les machines dans les territoires enclavés), (iii) les conflits et l'insécurité à l'Est et (iv) la pénurie annoncée des énergéticiens.

La formation des énergéticiens, la recherche-développement, l'innovation et la connaissance approfondie du potentiel national d'EnR requièrent davantage d'efforts du Gouvernement et de tous les acteurs de l'industrie de l'électricité en RDC (y compris les universités).

Mots clés : fracture énergétique - efficacité énergétique - ressources énergétiques - industrie de l'électricité - mécanismes innovants de financement – formation des énergéticiens.f

Pelletized agricultural residues as alternative cooking fuel for Africa

Christian Rakos
proPellets Austria

Densification of biomass by pelletization is a technology that has expanded enormously over the last two decades - from a global production of 2 million tons in the year 2000 to over 40 million tons in 2020. The reason for this development is, that it is the most economic way of upgrading biomass to a fuel with consistent properties and high energy density. While pelletization was used in the past years mainly to upgrade wood residues and low grade wood, it can be also be used to densify agricultural residues such as rice husks, bagasse, and various types of straw. With the most recent advances of gasifying cookstoves such pellets can be used as a clean burning alternative to firewood and charcoal. The presentation will discuss first experiences with introducing rice husk pellets and improved gasifying cookstoves in Kampala, Uganda and assess the potential of this technology to be widely used in Africa.

Renewable Energy (RE) penetration rate: Reliable energy, Energy accounting and Energy Indicators for African countries

Yezouma Coulibaly
Prof Dr, 2iE, Ouagadougou

Une difficulté majeure rencontrée par les pays africains est la mise en place de comptabilités énergétiques fiables. Celles-ci permettent d'exprimer toutes les productions, transformations et consommations des formes d'énergie d'un pays dans une même unité et dans un même tableau, l'objectif final étant la détermination des indicateurs énergétiques tels que :

- La consommation d'énergie finale par tête d'habitant
- La consommation désagrégée et chiffrée des différents secteurs de la vie économique
- L'intensité énergétique du PIB
- L'indépendance énergétique du pays
- Les parts des énergies conventionnelles, renouvelables, traditionnelles

En Afrique, la prise en compte de cette dernière forme d'énergie dans une comptabilité énergétique est un vrai casse-tête pour les spécialistes de la question. La faute revient à l'insuffisance de formation et de recherche dans ce domaine.

La présente étude se propose de présenter l'importance de l'établissement de comptabilités énergétiques et comment elles sont indispensables pour la mise en place d'une bonne politique énergétique.

Elle passe en revue les problèmes rencontrés à chaque niveau de données statistiques et montre comment il est indispensable que les formateurs et chercheurs du continent s'attèle à la résolution de ce problème des comptabilités énergétiques nationales. Un des objectifs in fine de ces comptabilités énergétiques est la connaissance précise des parts des énergies renouvelables dans le mix énergétique de chaque pays.

Hydrogen : a Sustainable Facilitator for Decentralised Electricity Production (and Consumption)

Joris Proost
UCLouvain,
RTD Centre for Process Engineering
(hydrogen)

Hydrogen produced from renewable electricity through Power-to-Hydrogen (P2H) can facilitate the integration of high levels of variable renewable electricity into the energy system. An electrolyser is a device that splits water into hydrogen and oxygen using electricity. When electricity is produced from renewable energy sources, the hydrogen becomes a carrier of renewable energy. Electrolysers can help integrate the variable renewable electricity into power systems, as their electricity consumption can be adjusted to follow wind and solar power generation, where hydrogen becomes a source of storage for renewable electricity. Although such hydrogen production technologies (especially alkaline and PEM electrolysers) are still further maturing, fossil parity for electrolytic hydrogen can already be achieved as of today in a number of sectors where hydrogen from renewables stands out as the best-performing option to meet climate targets and comply with local emissions regulations. Moreover, based on state-of-the art CAPEX and OPEX data for electrolysers, the necessary scale for obtaining such fossil parity can be surprisingly small, on the order of a few MW only. Such small-scale fossil parity for electrolytic hydrogen has the important advantage of allowing a de-centralised local H2 production. In that case, renewables can be harvested anywhere, and used directly for the local production and consumption of green, electrolytic hydrogen. This is a significant paradigm shift with respect to the fossil fuels based centralised hydrogen production at refineries, the latter also requiring an additional cost to transport the H2, both in terms of Euro/kg and CO2 footprint.

Western Africa's year-round even swell waves could produce more reliable, renewable power than even the vigorous waves of Northern Europe

Laurent Albert,
CEO Seabased,

Francisco Francisco,
PhD, Energy and Environment Manager,
Seabased

Sustainable development depends on access to, and quality of, electricity. Currently only about 10% of the electricity distributed by the world's grids comes from variable renewable energy sources such as wind and sun because grids must have a reliable power source to deliver a predictable baseload of electricity to their end users. When the sun sets or the wind stops, they must turn to a flexible power source such as diesel.

Wave energy, however, is a reliable and predictable source of variable renewable energy. Grid operators can know, from 5-to-14 days before they need the energy, what amount of the baseload wave can provide.

Several studies have determined that the wave climate in parts of West Africa is optimal for wave energy to be incorporated into the renewable mix. Such a move would not only increase the potential baseload and reduce the intermittency issues of using renewables but would allow renewables such as solar and wind to sell more of their power because, in tandem with wave, their intermittency is reduced.

It has long been assumed that wave energy is only an option where the wave climate is vigorous, such as Northern Europe. However, our studies show that a more moderate, steady swell wave climate may be even more promising in terms of power production. West Africa's wave climate is mild, with annual mean values of significant wave heights between 1-1.5 m, energy period of ca. 8-12 s and wave power value of ca. 6-12kW/m. The availability, capacity factors and electricity generation are estimated to be high most of the year except for November and December. An installed capacity of 100MW, yields to an estimated annual electricity generation of ca. 340GWh for a capacity factor of 40%. The annual resource availability factor is ca. 80%, which is high when compared to several other parts of the world with stronger climates. In terms of electricity conversion, this study concludes that though the wave climate of West Africa is not dramatic, it is sufficiently steady to produce a significant portion of the area's electricity year-round.

Mini hydro as an off-grid electricity solution for communities in villages in Africa, South America and Asia

Patrick Hendrick
(ULB – VUB – KULeuven)

For isolated energy systems, or off-grid systems, and local energy communities, due to the variability of natural sources, the combination of sources with a suitable (small) storage system reduces or solves the intermittency problem and the match between demand and generation, in addition to contributing to the decarbonization of the local energy system. Several studies have shown the technical feasibility and potential use of renewable hybrid energy production systems, using solar and wind sources with pumped storage and a small pack of batteries (10-20 kWh).

As a first example, in Tucuruí, Amazon region, Brazil, in the construction of the hydroelectric plant, due to the topography of the region, after the formation of the water reservoir, more than 1700 islands were created, which, due to geographic, technical, political factors do not currently have connection to the local distribution grid. Presently, all communities located there seek to supply their own energy demand using diesel generators, known for their very polluting emissions and high long-term costs.

A second example will be considered for a very poor African country as Burundi.For the case of Burundi, for example, the over-dependence on hydropower as the main energy source for its power supply has been hampering its economy. Its total power supply registered a reduction of 40 % due to a reduced volume of water in 2009. However, this country is endowed with many options for renewable energies (RE) such as hydropower and solar PV. As there are not enough fossil fuel resources discovered yet, RE is a more important strategic component for diversification of its national energy supply. The objective of this presentation is to demonstrate the viability of a hybrid system using solar PV (and, even better, floating PV or FPV) with pumped hydro energy storage (PHES) and small battery energy storage (BES) applied to an off-grid population. This hybrid solution can bring all electricity needs to rural population in African countries at a very reasonable cost (LCOE) of roughly 5-10 c€/kWh, with a minimum maintenance requested and a long lifetime of the complete solution. This can be implemented together between the national organizations as Ministries and central administration, supporting financially, the local population and its small manufacturers and workshops and, finally, universities helping for the design and implementation of the hybrid solution and the training of the local agents.

In both cases, Amazonia and Burundi, the PHES solution that is proposed is to use low cost global solutions, as PaTs (Pump-as-Turbines) or BMT (Banki-Michell Turbines or Cross-Flow Turbines).

The example of an island in the dam lake region of the Tucuruí powerplant, in Brazil, will be completely explained. When sizing the proposed system, the use of a PaT with variable speed and the rational use of water are adopted as criteria. The hybrid system proposed is compared with a single PV system currently installed, in order to analyze the feasibility and the implementation advantages. The proposed system proved to be technically and economically attractive, fully meeting the demand with a PaT energy around 6.3 kW in pump mode and 11.2 kW in turbine mode, for one day of operation. Working with a volume of water of 129 m3, the project guarantees a payback period of 2.5-3 years only.

Energy systems that are secured, competitive and affordable, and compatible with a sustainable and inclusive development of the continent.

Wisdom Ahiataku-Togobo

Director for Renewable and Alternative Energies
Ministry of Energy, Republic of Ghana.

Sustainability is at the heart of energy policies these days. Globally, countries are promoting access to affordable energy to improve the living standards of their citizens and to meet their development goals. Energy is an important topic in international politics. It is scarce and affects so many aspects of the global economy. That is why, it is important to determine the sustainability of energy systems. (Grigoroudis et al., 2019). Technologies that harness energy from natural sources in the form of biomass, wind, solar, hydro and many others are being adapted by countries all over the world because of wide-spread belief of their sustainability (Carley, 2009; Sawin and Flavin, 2006). Unfortunately, utility scale deployment of these technologies has not been very successful in most sub-Saharan African countries.

To ensure that the technologies for harnessing these energy sources are indeed sustainable, it is important for an assessment to be conducted before any decision is made. (Grunwald, 2011). The United Nations refers to three dimensions of sustainable development; the economic, social, and environmental dimensions which have formed the basis of sustainability as far as the United Nations and its Sustainable Development Goals are concerned.

This presentation will challenge the assumptions that renewable energy technologies are likely to be sustainable in a country, simply because the energy sources are.

It will look at sustainable energy technologies within the context of sub-Saharan Africa to ascertain their "sustainability" and the policy considerations that must be made in choosing them. It will go further to propose a model for determining sustainability taking into consideration country context and conditions.

Innovex, a producer of IoT digital tools made in Africa for off-grid energy systems

Douglas Baguma,
Managing director at Innovex
Uganda

Innovex is a technology company with hardware and software development teams offering a service 100% made in Africa. Innovex aims to spur Africa's social-economic transformation through the development of novel technologies. The key company competences include embedded systems, connected devices, web and software development, and wireless communication technologies. The company was founded in 2016 by Douglas Baguma K and David Tusubira, both graduated from the Makerere University. The 2 co-founders came to the realization that solar energy had the potential to bridge the energy access gap for the 30 million Ugandans remaining without electricity, but were frustrated the technology was not reaching Ugandans fast enough. Douglas & David took on this problem by helping installers and distributors of off-grid solar energy systems to scale up using digital tools. There are 300 active solar companies in Uganda alone, and thousands more in sub-Saharan Africa.

The team has developed 'Remot', a cloud-based IoT solution enabling solar companies, EPC and distributors to remotely monitor and manage their energy systems. Innovex's 'Remot' system consists of a locally manufactured smart meter and an in-house cloud-based web system. The smart meter tracks a number of parameters from the solar system including; solar production, battery health, and load consumption. This data is then sent wirelessly to the cloud-based web platform. Using data analytics, the cloud-based platform provides useful performance information and key system alerts such as; battery state of charge, system overload, and extreme ambient and battery temperatures alerts. With these data driven features, solar companies can remotely diagnose any faults and quickly respond to prevent product breakdowns. Technicians are able to establish points of failure prior to site visits, allowing them to respond with the appropriate components and knowledge necessary to conduct repairs.

'Remot' has transformed the way many of these solar companies do business such as better aftersales support and opening up pay-as-you-go for larger size solar systems. This has reduced overall downtime and improved accessibility of solar systems and equipment. Many of these solar assets are installed in facilities such as health centers, schools and SMEs across the 5 countries in the East African region i.e. Uganda, Kenya, Tanzania, DRC and Ethiopia.

Innovex stands out as a true African grown inspiration and has received support and recognition on the international stage from partners such as OVO, CISCO, Energy 4 Impact, the Netherland Trust Fund (NTF). The company received additional extensive support from the Royal Academy of Engineering in the UK, Energy Saving Trust under the Efficiency for Access Coalition and later the Carbon Trust under the Transforming Energy Access program.

Working with the Carbon Trust under the Transforming Energy Access (TEA) program Innovex has established a local SMT and plastic manufacturing facility for its products. This establishment seeks to ensure local value addition by providing better job opportunities for local product developers in the solar energy space while increasing accessibility to product spare parts. Innovex has also stimulated the local product development industry by sourcing product components and making them available at affordable prices on the local market.

Challenges of long term power system transition in West Africa: the case of the Ivory Coast

Edi Assoumou,
Center for Applied Mathematics,
Mines ParisTech, PS

One of the most pressing development issues for West Africa is the need for a rapid expansion of a currently undersized power system in order to fuel its economic development objectives and enhance the living conditions of a fast growing population. Power consumption per capita in the region is typically less than 5% its levels in OECD countries. Yet if electricity access is, and should be, the short to medium term priority, this need for more installed capacities will also have to take into account the overarching target of a transition towards a sustainable energy system in the second half of this century.

In this research work we will review the main power system expansion issues for West Africa and illustrate the implications of a cost optimal transition towards a low carbon power system for the case of the Ivory Coast. We will focus on a medium term horizon, 2030, as well as the longer term, 2050, which is necessary to account for the inertia in investment decisions. Our assessment is based on a TIMES model for the power system of the Ivory Coast. The model minimizes the total discounted cost of the system over the simulation horizon and computes a consistent trajectory. We compare 4 prospective scenarios and discuss the outcomes of each scenario in terms of production costs, investment needs, independence, CO2 emissions and potential jobs.

Nuclear Energy Tomorrow as Critical Enabler towards a Sustainable Future

Luc Van Den DURPE
Partner Road-to-Nuclear

Jean-Jacques Gautrot
Partner Road-to-Nuclear

Henri Zaccai
Partner Road-to-Nuclear

Sylvain Hercberg
Partner Road-to-Nuclear

Nuclear energy is again seen as a critical enabler for global socio-economic development and prosperity while preserving our environment. Nuclear energy has been contributing since the 1960s to a decarbonized, safe and economic energy generation providing energy independency and stable forecastable pricing, broad economic benefits as high-level jobs and industrial capabilities, and welfare to nations benefiting from the nuclear science and technology applications as food safety, biodiversity preservation and nuclear medicine.

While most nuclear power parks around the world are essentially light-water reactor (LWR) based providing primarily electricity, our sustainable energy needs will need not only an increasing amount of electricity but also process heat for water desalination, industrial processes, district heating and generation of hydrogen for a variety of applications. While LWRs will remain the backbone for many nuclear power parks around the world, the introduction of Small Modular Reactors (SMRs) and even more Advanced Nuclear Reactors (ANRs) may bring more market-adapted nuclear energy solutions for emerging and specific applications for nuclear energy.

This presentation will bring a summary of:

- The developments worldwide regarding SMRs and ANRs with particular focus on developments within the USA, Canada and Europe;
- The expected timeline for such SMRs and ANRs and the prospects they may bring for African countries;
- The expected economics for such tomorrow's nuclear, and;
- The options for associated fuel cycle and waste management.

The paper and presentation will provide the attendees an up-to-date view on the key development challenges for such more market-adapted nuclear energy solutions and the prospects such developments may provide to African countries in their decision-making regarding nuclear energy use.

The Conundrum of Sustainability of Hydro-Electric Energy as a Renewable Energy Source under Climate Change: Implications for the Resilience of the Water-Energy-Food Nexus of Southern Africa

Joseph Thokozani Mwale, Mulungushi
University, School of Agriculture and Natural Resources,
Kabwe, Zambia

The global concerted effort of ensuring energy security for all people is premised on the perceived sustainability of renewable energy resources such as hydro-electric energy, solar energy, and wind energy. This disposition is shaped by the lived human experience of the negative effects of intensifying the use of fossil fuels for energy generation. In the Anthropocene age of the Earth's history during which industrial production, mining, and agricultural production are intensified to meet the socio-economic needs of the burgeoning human population, Global Environmental Change (GEC) has emerged as an extraordinary outcome of the human-environment interaction. Central to the challenge of the 21st century within the Anthropocene period is the Climate Change phenomenon. Climate change, evidenced by long-term shifts in weather parameters, is predicted to bring unprecedented social and environmental transformations in the regions of the world that notably have low adaptive capacity. While the scientific evidence of climate change is overwhelming, the transformations it induces at local scales are poorly understood from the sustainability perspective. This creates a knowledge gap for policy decision-making and pragmatic action on managing the syndromes of climate change impacts such as increased water scarcity for water supply and sanitation, food production, and hydro-power generation. The scientific discourse of this presentation is focused on the sustainability of hydro-electric energy as a renewable source of energy under the climate change scenario.

Hydro-electric energy is interrogated for sustainability through the Complex Adaptive Systems (CAS) theory, which is increasingly seen as a scientific frontier transcending the natural and social science disciplines, and having a profound effect on the future of science, engineering, and industry. Complex adaptive systems are typically characterised by co-evolutionary dynamics based on complex behaviour that emerges from the interactions among system components and their environment. Within this theoretical perspective, a co-evolutionary approach is used to navigate the resilience of the water-energy-food nexus of Southern Africa against the syndrome of unsustainability of hydro-electric energy as a renewable energy source under climate change.

Under the changing context of socio-economic development in Southern Africa that is characterised by high population growth rates, high energy demands, inter-annual variability of temperature and rainfall; the viability of hydro-electric energy as a source of energy within the water-energy-food nexus is uncertain. Given that the survival of human civilisation critically depends on the water-energy-food nexus to a larger extent, quantitative understanding of the co-evolutionary dynamics of climate change and water availability for the water-energy-food nexus is essential. Therefore, the co-evolutionary perspective reveals a spectrum of interdependencies, synergies and trade-offs in the water-energy-food nexus under a changing climate. To this end, the vision of a sustainable energy future for Africa under the context of climate change is critically dependent on a robust triple helix model of science, technology, and innovation to develop adaptive capacities and higher levels of resilience in the face of climate change. This calls for science-policy dialogue to create an enabling environment, linkages, and stakeholder partnerships for young scientists to navigate the complex development challenges of our time.

Calcul de l'écoulement de puissance dans les réseaux de transport électrique par la méthode de Newton-Raphson : application au réseau de

transport électrique de la Communauté Electrique du Bénin

Mawuéna MEDEWOU,
UAC Bénin,
Taskforce chargée de la rédaction des procédures d'exploitation
du réseau interconnecté du WAPP

Dans le cadre du projet d'interconnexion des réseaux électriques des pays membres de la CEDEAO porté par le Système d'Echange d'energie Electrique Ouest-Africain (EEEOA), des directives d'exploitation ont été définies par l'Autorité Régionale de Régulation du Secteur de l'Electricité de la CEDEAO (ARREC) en vue d'assurer une exploitation efficiente du réseau interconnecté. Chaque opérateur s'oblige à respecter ces directives aux fins de garantir la stabilité et la fiabilité de la fourniture de l'énergie aux pays de la CEDEAO.

Ce document a pour objet, de réaliser l'étude de l'écoulement de charge sur le réseau de transport existant de la CEB et de proposer des solutions notamment pour le respect des exigences relatives au niveau de tension requis sur les lignes d'interconnexion ou aux points de raccordement avec les opérateurs voisins. Après l'inventaire des infrastructures de transport et de production de la CEB et le relevé des charges sur les points de consommation, un modèle de son réseau a été réalisé ainsi que le schéma unifilaire.

Le calcul de l'écoulement de charge a été réalisé avec l'algorithme de Newton-Raphson et les tensions aux nœuds ont été calculées à l'aide du logiciel CYME. A partir des tensions calculées aux divers nœuds, des solutions d'amélioration ont été proposées pour ramener les niveaux de tension aux valeurs admises par l'autorité de régulation.

Energy Challenge in Africa using case study of AET innovations in energy efficiency

Sandiswa Qayi,
woman social scientist and economic development practitioner, innovator,
Managing Director of AET (Amahlathi Eco-Tech),
AFRICA Eastern Cape South Africa

Abstract

Majority of African countries have seen increasing demand of energy brought by urbanization and meaningful economic growth in major cities. This growth in order to be sustainable there is a need for sustainable, accessible, affordable and efficient energy usage. Despite energy mix strategies and policies, the continent is still far below the sustainable development goals in addressing the issues. Majority of African countries such as South Africa are still battling the challenge of continuous rising electricity prices, load shedding or power failures caused by excess energy consumption that result in poor access to affordable and sustainable energy to sustain economic growth. Not only these challenges affect the economic growth but contributes to serious carbon emissions by coal power stations. Despite existing alternative energy sources such as solar, wind and hydro energy, coal power stations to generate electricity for majority of citizens are still primary source of energy supply that can be accessed by majority of people. Excess demand versus limited supply of electricity results in load shedding and interrupted power supplies that results in high electricity costs and further marginalised the poor people as they cannot easily afford alternative solutions hence the need for retrofit solutions.

The paper argues for prioritization of energy efficiency retrofit solution as alternative solution into the energy mix to address the energy challenge in Africa regarding affordability, sustainability and accessibility. The paper addresses this issue by using case study of AET AFRICA water heating and cooling innovations Hotspot and Heat Raiders as retrofit energy efficiency solutions to address the energy challenge in Africa. The two innovations are locally designed and manufactured in South Africa as retrofit solutions for water heaters and cooling devices to address water heating needs and cooling using existing devices. The paper provides this rationale by arguing that water heating and cooling are the biggest energy consumers in ordinary urban settings due to demand for sanitary water and cooling due to climate conditions in Africa. These solutions can improve energy efficiency and reduce energy costs by 30-40% on monthly basis for each household thus improve accessibility to sustainable and affordable energy. This can be achieved by using energy supply from existing coal powered stations to ensure continuous supply of electricity with

limited load shedding currently experienced in countries such as South Africa due to high energy consumption caused by inefficient energy usage. These solutions need to be customised for African socio-economic market conditions to ensure affordability and easy installations. The roll out of these devices will not only reduce energy consumption and improve energy efficiency but will significantly contribute to economic growth and job creations as they can be easily manufactured and installed by local people to promote job creations and reduce poverty. Job creation and income generation will then have a bigger economic impact in terms of using energy to address economic development challenges in Africa. The paper understands the limitations of these solutions and that they are not the only solutions but can play a significant role as part of energy mix in addressing the energy challenges especially in countries with high energy usage and demand for water heating and cooling.

Natural Gas Use and Perspectives: Opportunities for Intra- and Inter- African Trade

Joseph Essandoh-Yeddu
Ex-Director, Strategic Planning and Policy
Energy Commission, Ghana

Africa's population currently stands at about 1.2 billion with over 80% in Sub-Saharan Africa and of which 60-70% live in rural and remote communities. Except for a handful, almost all the African countries are classified as least developed or low-income economies. The continent's share of global primary energy consumption is estimated around 3% and is largely traditional biomass accounting for 60-90% and which has been linked to unsustainable practices and deforestation. Currently, about 900 million of the inhabitants lack access to clean and modern cooking fuels like gas. Except for South Africa, Ghana and the northern region along the Mediterranean where electrification rates exceed 85%, the average for the rest of the continent is about 45%. Even where it is available, it is largely known to be unstable, intermittent and consequently unreliable. The continent's overall population is projected to double by 2050 accounting for 25-26% of the global population in 2050 with over 50-60% living in urban areas. These profound changes are expected to drive the continent's economic growth, infrastructure development and, particularly, energy demand which is projected to exceed 1,320 MTOE in 2050, based on existing policies/plans.

Africa however has unique opportunities to pursue a much less carbon-intensive development path based on natural gas to boost clean cooking, electrification access, also compressed-natural-gas (CNG) as clean transport fuel. Africa currently consumes about 110 billion cubic metres which is about 51% of its production. The remainder is largely exported as a primary commodity. Any domestic use is largely for power generation. But unlike oil where the commodity could just be exported without necessarily developing the local market, natural gas requires greater local infrastructure development being it as LNG for export, CNG, or as feedstock for local petrochemical industrialisation, the latter being larger. Gas petrochemical value-chain products include fertilizer, detergents, plastic packaging, lubricants, pharmaceuticals, artificial leathers, adhesives, refrigerants, etc. Revenue from the global petrochemical market is expected to double by 2022 from $550 billion in 2014.

Besides the existing offshore exports, Africa has the potential to promote intra-African trade using the continent's huge gas reserves estimated around 17.7 trillion cubic metres and taking advantage of the existing regional gas pipeline integration which includes West African pipeline (WAGP), Trans-med; Mozambique -South Africa, and could be extended and integrated to form a closed loop around the continent. Such an Intra-African Trade can take advantage of the Africa Continental Free Trade Area pact signed in 2020; which intends to guarantee larger market, Tariff/Duty free exports, decrease trade restrictions, etc. creating opportunities for countries to share advantages in terms of resources or energy supply for instance, justifying investments in small resource market-economies to export to bigger cross-border economies.

Presentation will cover the developments since the completion of the WAGP over a decade ago, the evolving natural gas market, trade (local and international), future market configuration and potential for inter- and intra-Africa trade.

IAEA's contribution to capacity building in Africa for sustainable nuclear energy solutions

Shaukat Abdulrazak,

The growing demand and limited access to energy in Africa is combined with the pressing global challenge of climate change and the imperative need for clean energy deployment required to meet the United Nations Sustainable Development Goals (SDGs). The International Atomic Energy Agency (IAEA), which mandate (1) is to promote the use of nuclear techniques and technologies for peaceful applications, joins the international community efforts to help Africa address this difficult equation.

The IAEA provides support to its Member States to apply nuclear technology safely and sustainably in different fields including for energy systems analysis and planning and supply. The Technical Cooperation Programme is the primary mechanism for the implementation of this support.

In the field of energy systems analysis and planning, the IAEA assists national teams build their capacities using the IAEA energy planning tools (2) including the Model of Analysis of Energy Demand (MAED) and the Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE)

Globally, 153 countries and 20 international organisations use those tools that are designed to help countries elaborate sustainable energy strategies and conduct studies for electricity supply and energy options, energy investment planning and energy environment policy formulation.

Recent achievements in Africa include the development of sub-regional energy plans for sustainable electricity supply options for West, East and North African sub-regions through the use of IAEA models. Currently, the IAEA is contributing to a very ambitious initiative led by the African Union Development Agency (AUDA-NEPAD) to develop a Continental Energy Master plan for Africa.

Energy planning is key to help identify the most cost-effective and environment-friendly energy system options, including the potential role of nuclear power. In Africa(3), nuclear contribution to electricity generation for 2020 accounted for 1.5% of total 803 TWh. It is expected that the share of nuclear electricity in total electricity production could be in the range 1.0-1.7% in 2030 and 2.0-3.3% by 2050.

The IAEA provides a wide range of services, support, expertise and guidance to those Member States considering or embarking on new, or expanding existing nuclear power programmes, and helps them apply the Milestones Approach(4), which is a management guide for nuclear power programme development. The IAEA conducts review missions, such as “Integrated Nuclear Infrastructure Review (INIR)” and offers guidelines on developing the necessary infrastructure for a safe, secure and sustainable nuclear power programme.

Currently, the IAEA is providing support to 12 African Member States who are investigating whether nuclear power is an option for addition into their energy supply mix or already developing their nuclear infrastructure for responsible deployment of nuclear power.

Harnessing waste-to-energy value chain to achieve sustainable development goals: lessons for Sub-Saharan Africa

Samuel A. Igbatayo
Director, Afe Babalola University Consult,

Waste-to-energy (WtE) value chain has emerged in recent times as an element of renewable energy resources around the world. This is particularly noteworthy against the challenges associated with fossil fuels-coal, crude oil and natural gas-which are increasingly assuming unpopular dimensions in the light of incessant price fluctuations, uncertainty, environmental challenges and the emergent global climate change. A United Nations Environment Programme (2018) report reveals global investment in renewable energy has risen to US$2.9 trillion since 2004, with China emerging, by far, the world’s largest investing country in renewable energy, at an unprecedented 45% of the US$279.8 billion worldwide investment committed to all renewable energy resources over the period 204-2017. In 2017, renewable energy accounted for an estimated 70% of net additions to global power capacity, attributable to continued improvements in the cost-competitiveness of both solar polyvoltaic (PV) and wind power. The emergent paradigm shift from fossil fuels to renewable energy is the major driving force propelling the growth of global waste-to-energy markets. The global WtE value chain is increasingly competitive. The market is projected to rise in value to US$31.8 billion by the end of 2019. Waste-to-energy (WtE) resources are in abundance in Sub-Saharan Africa, against an emergent demographic explosion, which is accompanied by rapid urbanization that is generating considerable municipal solid wastes. While Europe and Asia lead the WtE markets, Sub-Saharan Africa lags is marginalized, constrained by the large upfront investment profile of WtE projects The International Energy Agency (2014) reveals that about 625 million people in Africa lacked access to electricity. In order to achieve universal access to energy, however, Africa requires an investment estimated at more than US$1.5trillion inthe energy sector between 2018 and 2050, spurring Africa’s development partners to launch “The lighting Africa” Programme, aimed at broadening access to energy. Therefore, WtE infrastructure is increasing gradually in Africa recognized as a tool to capture energy for delivery to marginalized communities in several countries. Accessibility to affordable and clean energy, which is associated with WtE technologies, is also critical to achieve the 2030 SDGs in Sub-Saharan Africa.

The major objective of this paper is to shed light on the waste-to-energy (WtE) value chain as a tool for sustainable energy in Sub-Saharan Africa. It employs both quantitative and qualitative analytical methods to explore global trends in WtE value chains and lessons for Sub-Saharan Africa. The paper relies on secondary data from a variety of international and national agencies, as well as scholarly journals and periodicals, complemented by interviews with stakeholders around the region.

Findings reveal an evolving adaptation of WtE technologies to capture renewable energy in Sub-Saharan Africa, but require considerable increase in investment on a pathway to sustainable energy.

Sustainable and Equitable Mobility for African Cities

Christopher Kost
Director of the Africa Program
Institute for Transportation and Development Policy
Nairobi, Kenya,

African cities are heavily reliant on walking, cycling, and public transport. Yet most ongoing transport investments in the region focus on the movement of cars, overlooking mobility for the majority of city residents. How can we repurpose transport investments to address mobility for all, especially vulnerable road users?

The talk will explore how cities can develop in high-quality walking and cycling facilities, efficient public transport, and better land use-transport integration, covering the following case studies among others:

• DART BRT: In 2016, Dar es Salaam launched the first phase of the city's bus rapid transit (BRT) system, the first BRT in East Africa. Serving the key axis of Morogoro Road, the first phase network spans 21 km. Trunk services ply from Kimara to Kivukoni ferry terminal in the city centre, and also along branches to Morocco junction and the Kariakoo market. Median-aligned dedicated lanes ensure that DART riders have fast and reliable commutes without interference from private vehicles and minibuses. The DART system has dramatically reduced commute times for Dar es Salaam residents, who previously faced upwards of 4 hours stuck in traffic each day. For passengers taking DART, a trip from Kimara to the city centre now takes only 45 minutes. In addition, most stations have overtaking lanes, allowing a portion of the fleet to provide express services to key destinations. The system serves over 172,000 passengers on trunk and feeder buses.

• Kisumu Triangle project: The City of Kisumu, Kenya, has begun implementing best practice designs that improve safety for pedestrians and cyclists in line with the Kisumu Sustainable Mobility Plan. Under the World Bank-financed Kenya Urban Support Program, the city launched the KES 241 million Kisumu Triangle project, involving the reconstruction of 1.5 km of walkways along Oginga Odinga Street, Ang'awa Avenue, and Jomo Kenyatta Highway. Tabletop pedestrian crossings were constructed to provide safe, universally accessible crossing points for pedestrians. The project also included storm water drainage improvements, installation of utility ducts, installation of solar street lights, and construction of public toilets.

Through cases of successful transformation, the session will illustrate measures that African cities can take to improve access to opportunities, redress urban inequality, and mitigate emissions of harmful pollutants.

Electrification des milieux ruraux par les micro-centrales hydroélectriques en RD Congo

Eddie BILITU
Ecole Supérieure des Ingénieurs Industriels/
Univ. de Lubumbashi, RDC)

Ce projet porte sur l'étude d'implantation d'une micro-centrale hydroélectrique sur la rivière Tshabula coulant dans le territoire de Mutshatsha province du Lualaba en RD Congo. L'objectif est d'exploiter le potentiel hydroélectrique de cette rivière en vue d'alimenter principalement le village Tshabula ainsi que les villages environnants qui sont restés non électrifiés pendant jusqu'à nos jours.

Pour y parvenir, nous avons effectué une série des descentes sur le site pour y évaluer les caractéristiques hydrauliques telles que le débit disponible et la hauteur de chute brute. Ces dernières ont permis de déterminer la puissance hydraulique exploitable sur le site. Il s'en est suivi le calcul de la puissance mécanique que développera la turbine hydraulique de la centrale. Ceci nous a conduit à la détermination de la puissance électrique que produira la future centrale hydroélectrique.

La puissance hydraulique de la rivière a été évalué à 1424,4kW soit environ 1,4MW. Au regard de cette puissance, le choix a été porté sur une turbine Kaplan à axe verticale capable de développer une puissance mécanique de

1281,9kW à une vitesse de rotation de 333tours/min. cette turbine entrainera un alternateur à pôles saillants de puissance électrique de 1,2 MW sous une tension composée de10kV et de fréquence 50 Hz.

Cette puissance électrique de 1,2MW est considérablement suffisante pour alimenter tout le village Tshabula ainsi que ses environs. Ce village compte une centaine d'habitations, une école primaire, un dispensaire et une maison de formation religieuse de frères salvatoriens. Vu que le Village à alimenter se trouve à environs 100m du site de production, un poste de transformation MT/BT sera installée entre la production et la zone de consommation pour distribuer directement les habitations. Ce poste de transformation aura pour fonction de ramener la tension de 10kV à 400V (en triphasé) ou 220V (en monophasé). Le réseau de distribution sera du type radial aérien adapté économiquement et techniquement au milieu rural.

Cette électrification du village Tshabula et ses environs constituera un puissant outil de de développement socio-économique. Elle permettra aussi de réduire l'utilisation de charbon et de bois de forêt comme énergie principale pour les besoins domestiques dans le village. Signalons qu'il n'existe quasiment pas d'activités économiques dans ce village. Sa population vit principalement de l'agriculture. Dans le milieu rural, la puissance consommée par ménage est estimée à 400W. Cette puissance fournie au village servira pour l'éclairage, le divertissement (téléviseur, radio). Avec l'arrivée de l'électricité dans le Village Tshabula pouvant engendrer une augmentation des besoins en énergie des ménages et une croissance démographique, cette puissance peut aller jusqu'à plus ou moins 800W par ménage. La puissance du transformateur MT/BT à installer sera de 100kVA. Deux autres postes MT/BT seront installés un peu plus loin pour alimenter les envirorns du Villages Tshabula (villages voisins :…..).

Le Projet CHARLU, vers une offre sécurisée en charbon de bois et une réduction de la déforestation du miombo autour de Lubumbashi (Haut-Katanga, RDC)

Yannick Useni Sikuzani
Doyen de la Faculté d'Architecture,Université de Lubumbashi (UNILU) , RDC

Jules Atchoglo
Togo

Jan Bogaert
Agro-BioTech, Université de Liège, Gembloux

François Malaisse
Agro-BioTech, Université de Liège, Gembloux, Belgique

Quentin Ponette
UCLouvain, Belgique,

Avec un indice de développement humain qui le place en 186ème position sur 187 et plus de 85% de la population qui vit avec moins de 1,25 USD par jour, la République Démocratique du Congo (RDC) fait simultanément face à des défis écologiques, démographiques et économiques majeurs : seulement 2,5% du potentiel du réseau hydroélectrique sont exploités pour assurer la desserte en énergie électrique. Dans la province du Haut-Katanga (Sud-est de la RDC), la libéralisation du secteur minier intervenue en 2002 a entraîné une explosion démographique suivie d'une augmentation de la demande en énergie. Toutefois, la desserte en électricité est caractérisée par la vétusté des installations ainsi que des délestages non planifiés. A Lubumbashi, principale ville du Haut-Katanga, les infrastructures électriques ne sont pas ajustées à l'expansion spatiale urbaine rapide et incontrôlée et les ménages développent des alternatives telles que la quête de bois-énergie pour la cuisson des aliments et des briques. En conséquence, les îlots forestiers régressent en superficie, se dégradent et disparaissent constamment. D'une part, nous avons apprécié la dynamique de l'occupation du sol au sein de la Réserve de Biosphère de Lufira (située à 80km de Lubumbashi) et sa périphérie à partir de l'analyse diachronique de cinq images satellitaires de type Landsat acquise entre 1979 et 2018. Les résultats indiquent qu'au sein de la RBL, les surfaces forestières ont chuté à 11,8 km² en 2018 contre 75,8 km² en 1979. Cette déforestation résulte de l'expansion des savanes boisées (+25,5 km²), ainsi que des champs et jachères (+46,6 km²). Ceci semble suggérer que la production de charbon de bois associée ou non à l'agriculture a été le processus sous-tendant la déforestation observée et qui a milité pour le déclassement de la RBL. D'autre part, nous avons initié un projet sur le renforcement des capacités de gestion durable de la forêt claire de miombo par l'évaluation de l'impact environnemental de la production de charbon de bois et l'amélioration des pratiques vis-à-vis des ressources forestières (CHARLU, 2020-2024). Ce projet vise à améliorer les pratiques de différents acteurs vis-à-vis des ressources forestières en (i) améliorant la gouvernance des ressources forestières, (ii) évaluant l'empreinte spatiale de la déforestation en vue d'envisager les plantations forestières à de fins énergétiques, (iii) en quantifiant les stocks des éléments nutritifs sur les espaces déboisés pour la carbonisation afin de les valoriser à travers l'agriculture (choix des espèces et variétés adaptées), (iv) militant pour l'organisation des producteurs du charbon de bois en association et (v) en optimalisant le rendement de carbonisation à travers l'amélioration des pratiques locales. In fine, l'exploitation et la gestion de la forêt claire de miombo autour de Lubumbashi seront améliorées suite à la transformation des pratiques de production de bois-énergie et d'agriculture itinérante.

A Review of Global Perspective on Geothermal Energy

ADEDAYO, Rotimi Muyiwa
Electrical Systems Engineer,
University of Ibadan, Ibadan Nigeria,

Electricity from geothermal energy had a modest start in 1904 at Larderello in the Tuscany region of northwestern Italy with an experimental 10 kW generator. Today, this form of renewable energy has grown to 15.4 GW in 26 countries of the world producing an estimated 95,098.40 GWh/yr. These "earth-heat" units operate with an average capacity factor of 71.4% (EIA Report, May, 2021); though, many are "on-line" over 97% of the time, providing almost continuous base-load power. This electricity production is serving an equivalent 102 million people throughout the world (Dauncey,2001) which is about one percent of our planet's population. The development of worldwide geothermal power production can be seen in Figure 1. The large downward spike in the production is the result of the destruction of the Italian field at the end of World War II (WWII). Just after WWII, geothermal power has grown at a rate of 6.2% annually. Electric power from geothermal energy, originally using steam from resources above 150oC, is now produced from resources down to 100oC using the Organic Rankine Cycle (ORC) process in binary power units in combination with a utility level heating project.

Etude de la performance d'un chauffe-eau solaire compact à absorbeur muni d'ailettes par le critère d'Entransy détruite

ADIHOU Coffi Wilfrid
UNSTIM, Abomey, Bénin,

AWANTO Christophe
UAC, Abomey-Calavi, Bénin

ANJORIN Malahimi
UAC, Abomey-Calavi, Bénin

HOUNGAN Comlan, Aristide
ENSET Lokossa, Benin

SANYA Adjibadé Emile
UNSTIM, Abomey, Bénin

Le présent travail s'est concentré sur l'utilisation du critère d'entransie détruite pour l'optimisation des dimensions des ailettes d'un absorbeur à ailettes pour un chauffe-eau solaire compact. Les dimensions optimisées sont le pas des ailettes sur l'absorbeur, le pas et la hauteur des ailettes dans le fluide caloporteur. Le fluide caloporteur utilisé est de l'eau et la surface du capteur est de 1 m2. Les modèles mathématiques des différentes formes d'entransy détruite ont été élaborés en fonction des propriétés physiques, thermiques et géométriques des différents composants du capteur et de l'eau. Les courbes montrant l'évolution de l'entransy totale détruite ont été tracées sous le logiciel Easyplot après une simulation dans Matlab. Les évolutions de ces courbes ont montré que le pas optimal des ailettes sur l'absorbeur est le plus faible possible, le pas optimal des ailettes dans l'eau est le plus grand pas possible et la hauteur optimale des ailettes immergées dépend du pas des ailettes sur l'absorbeur et la vitesse de l'eau. La différence entre la température de l'absorbeur et celle de la vitre influence les performances du capteur solaire plan.

NB Definition of entransy :

Entransy (thermodynamics) Half the product of internal thermal energy and temperature. For a given temperature difference, maximization of the entransy dissipation results in the maximum heat flux and thus corresponds to the optimal heat conduction performance.

Identification des modes d'exploitation des modules photovoltaïques dans la ville de Lubumbashi

Eddie BILITU
Enseignant chercheur
Université de Lubumbashi/RD Congo

La baisse de niveau de la qualité de service électrique en RD Congo a conduit la population à l'utilisation des sources d'énergie électrique alternatives telles que les groupes électrogènes, les modules photovoltaïques ou les petites centrales hydroélectriques. Une étude (Banza et al, 2018) récente a montré qu'environ 3% des ménages sur un échantillon de 5270 font recours à l'énergie photovoltaïque dans la ville de Lubumbashi. Le total des ménages dans la ville est estimé à 230 000. Par extrapolation, on trouve aisément qu'environ 6900 ménages utilisent les modules PV.

Au regard des caprices météorologiques, les équipements PV doivent être utilisés avec rationalité pour les faire fonctionner dans leur zone de rendement optimal.

Pour ce faire, les installateurs et les utilisateurs des équipements sont tenus à être formés et informés sur leurs modes d'utilisation. D'où l'importance de notre projet intitulé « IDENTIFICATION DES MODES D'EXPLOITATION DES MODULES PHOTOVOLTAÏQUES DANS LA VILLE DE LUBUMBASHI »

L'objectif de ce projet est d'Identifier les conditions d'utilisation des modules photovoltaïques dans la ville de Lubumbashi afin de les caractériser. Pour mener à bien notre projet et à cause des contraintes budgétaires et temporaires, nous avons été amené à déterminer la taille de l'échantillon par la formule de Rea. Et nous avons obtenu une taille minimale de l'échantillon des ménages sites photovoltaïques de 113 ménages.

Les premiers résultats ont montré que 42% des modules photovoltaïques ont été installés et exploités en moins d'une année dans la ville de Lubumbashi. Ceci prouve que la population de cette ville s'intéresse de plus en plus à l'énergie photovoltaïque. Les mêmes résultats ont montré les installations photovoltaïques sont plus majoritairement utilisées dans les résidences (maisons d'habitation) que les commerces. Les modules monocristallins sont les plus utilisés dans cette ville et les modules polycristallins n'y sont utilisés qu'à 38%.Environ 41% de modules PV utilisés sont inclinés de 0 à 30° vers le nord. En fonction de la latitude de la ville, l'orientation pour un rendement maximal des modules PV est d'environ 16°nord.

Pour faire face au problème de l'intermittence de l'énergie solaire qui varie annuellement entre 4 et 7kWh/m2, les ménages utilisateurs de modules PV recourent aux batteries Pb-acide comme moyens de stockage d'énergie. Ces batteries, plus rependues sur le marché lushois, ont une durée de vie de 400 à 800 recharges. Moins de 10% de ménages à Lubumbashi, au revenu moyen, recourent à l'utilisation de batteries Li-ion à cause de leur prix relativement élevé. La capacité de batteries Pb-acide utilisées dans les ménages à Lubumbashi varie entre 50 et 500Ah. Cette plage de capacité de batteries offre une autonomie d'un à deux jours pour un ménage utilisant des appareils moins énergivores tels que les lampes économiques (lampes LED, etc.), les téléviseurs LED, la charge des téléphones portables, etc.

Use of sorption materials in solar dryers for sustainable production

Rock Aymar DAKE
2iE, Ouagadougou, Burkina Faso.

Frédéric KUZNIK

Igor W. K. OUEDRAOGO
2iE, Ouagadougou, Burkina Faso.

Babacar LEYE

Kokouvi Edem N'TSOUKPOE
2iE, Ouagadougou, Burkina Faso.

Among the efforts to reduce post-harvest losses, drying techniques have been broadly used, especially solar drying techniques (Prakash et Kumar, 2017). Unfortunately, due to day/night cycles, solar dryers suffer from discontinuity in the drying process, resulting in long drying times. To tackle this problem, many researchers have worked on some concepts (Bal et al., 2011; Bal, Satya, et Naik, 2010) in the last decades, including the use of sorption materials. In this work, we review the various applications and concepts regarding the use of sorption materials in solar dryers.

In Africa, some projects have been identified at the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana (Amankwah, 2019); the Kenyatta University School of Engineering and Technology in Nairobi (Thoruwa, 1996; Thoruwa et al., 1998; 2000), Kenya, and at the Department of Mechanical and Electrical Engineering at Tanta University in Egypt. Basically, two types of applications of sorption materials in solar dryers were found in the different projects: one as a dehumidifier and the other as a thermal storage medium. Sorption beds used as dehumidifier aim at reducing the relative humidity of the drying air in order to increase its drying potential. The operating principle of sorption thermal storage is based on reversible physico-chemical phenomena, which are used to store energy. In both cases, interest has been found in the literature for silica gel and a composite material consisting of a mixture of bentonite, $CaCl_2$, vermiculite and cement in the ratio 6:1:2:1. Overall, solar dryers with integrated sorption materials were found to be technically more advantageous than conventional solar dryers, especially in terms of drying time. The incorporation of a sorption dehumidifier in a solar dryer, usually at the solar collector inlet, generally leads to a reduction of the drying time of 15-30%, although values up to 50% and even 64% have been reported. On the other hand, introducing sorption materials as thermal storage in a solar dryer, mostly integrated at the top in the drying chamber, usually leads to a reduction of the drying time in a range of 30-45%.

With reference to this review, the challenges regarding the use of sorption materials in solar dryers were identified. Following these conclusions, a case study is currently underway in Burkina Faso at the International Institute for Water and Environmental Engineering (2iE), focusing on mangoes drying with solar dryers. The objective of the study is to evaluate the time saving achieved by the combination of the innovations "dehumidifier" and "thermal storage" based on silica gel in a solar dryer designed for mango drying. The prototype investigated is an indirect solar dryer with forced convection mainly composed of a drying chamber, dehumidification units, a thermal storage bed, and a flat plate solar collector of 2 m² provided with baffles.

Transformation des résidus agricoles, forestiers et déchets biodégradables en ‘charbon vert’

Pierre KPANTINGNANGAN
DG de la Société des Énergies de Demain (SED Sarl)

La production de biogaz par nos digesteurs vise à produire une énergie propre et abordable en remplacement de l’énergie du bois de chauffe qui produisent les gaz à effet de serre.

La gestion des matières organiques (déjection animale, sang d’abattage, résidus alimentaires et végétaux divers, etc.) cause des nuisances et pose des problèmes sanitaires. Afin de faire face à ces défis, la Société des Énergies de Demain SARL promeut un système intégré permettant de recycler et de valoriser les résidus organiques issus de la production agricole (déjections animales, résidus de culture et de plantes envahissantes, effluents de transformation d’huile de palme, d’ananas, etc.) pour une production agricole durable elle-même en positionnant la bioénergie contenue dans ces biomasses au centre du système. S’inspirant de l’ingénierie écologique pour boucler les cycles de la matière organique tout en produisant de l’énergie décentralisée.

L’emploi d’un digesteur à biogaz a pour but de récupérer le gaz méthane émanant des matières animales et de matières végétales afin de produire du gaz domestique utile pour la cuisine.

Nous concevons, fabriquons et commercialisons au Bénin deux modèles de bio digesteurs qui produisent respectivement 4 m3 et 1,8 m3 de gaz par mois. Un destiné aux collectivités et aux fermes qui nécessite un lourd financement et une grande quantité de matière première. Le second modèle déplaçable, facile à installer est destiné à la fois aux ménages urbains et ruraux. La majorité des composants entrant dans la fabrication de ces deux modèles proviennent du Bénin même. Seuls quelques composants tels que sac digesteur et micro-organismes sont importés d’Israël et d’autres pays du fait de l’absence d’usine de fabrication et de la technologie de pointe de ces composants en Afrique.

En moyenne 50 kits du second modèle sont installés par an à des clients potentiels qui d’ailleurs sont venus vers nous grâce à nos activités d’exposition, de prospection et autres. Par contre 34 kits du premier modèle sont installés pour les collectivités et fermes avicoles. Les activités de production, d’installation et de vente de kit à biogaz représente en moyenne 45% de nos chiffres d’affaires annuels. Elle est donc bénéficiaire pour entreprise.

Transformation des résidus agricoles et déchets biodégradables en ‘biogaz’

Pierre KPANTINGNANGAN

La production de charbon vert vise à produire de l'énergie thermique en remplacement du charbon de bois.

Notre atelier de production de charbon vert, situé dans l'arrondissement de Godomey, commune d'Abomey-Calavi, est approvisionné par une grande quantité de matières premières telles que : tiges de maïs ; balle de riz ; fane d'arachide, déchet de scierie, du liant (amidon, gomme arabique…) et de l'eau. Après collecte, découpage en de petits morceaux et séchage des matières, les matières sèches sont carbonisées et compactées avec les déchets verts. Enfin les morceaux de charbon sont séchés.

Nous produisons soixante-quinze (75) kilogrammes de charbon par semaine soit cinq mille quatre cent (5400) kilogrammes de charbon bio par an grâce à deux travailleurs à mi-temps rémunérés à 15000 FCFA le mois. Notre entreprise se finance en vendant directement à 200 FCFA le kilogramme (contre 250 FCFA pour le charbon de bois).

Nous approvisionnons 20 consommateurs finaux dont les ménages et le collectif d'utilisateurs de charbon de bois. La majorité des clients sont venus vers nous lors d'une prospection porte-à-porte donnant droit à une sorte d'incitation aux premiers abonnés.

Aujourd'hui, nous comptons vingt (20) clients actifs avec comme projection cent (100) clients venant de partout à l'horizon 2025. Cette activité occupe en moyenne 10% de notre chiffre d'affaire annuel.

Réduction de la pollution harmonique du réseau de distribution électrique par un contrôle à base d'un filtre actif

Guy Masudi
Ecole supérieure des ingénieurs industriels Université de Lubumbashi,RDC

Fiston Tshibambe
AEMI SA Lubumbashi / Groupe Forrest International (GFI),RDC

Bonaventure Banza
Ecole supérieure des ingénieurs industriels 1 Université de Lubumbashi,RDC

Amos Ntambwe
Société Nationale de l'Electricité (SNEL), RDC

Malgré son puissant réseau hydroélectrique, la Société Nationale d'Electricité (SNEL) de la RDC n'exploite que 2,5 % de ce potentiel (soit 2 516 MW) pour assurer seulement 30 % de desserte en milieu urbain. Le déficit d'offre en électricité s'explique par la vétusté de la plupart des installations et le faible taux d'équipement dus au non-investissement systématique. Dans la ville de Lubumbashi, la population qui vit avec moins de 1,25$ USD par jour se rétracte sur le secteur informel pour la survie. Dans la Commune de Katuba, le développement des ateliers électriques ainsi que la pullulation des bureautiques en réponse au chômage quasi-généralisé que connait la ville a entraîné une distorsion des signaux de tension et de courant. Par ailleurs, depuis près de 7 ans, et à travers un partenariat public-privé, l'Atelier d'Electro-Maintenance Industrielle (AEMI) accompagne la SNEL dans la recherche des pistes de solutions pour améliorer la qualité de l'électricité offerte au niveau des ménages. Pour cette raison, cet atelier a mené une étude dans l'optique de quantifier la réduction de la pollution harmonique du réseau de distribution électrique de la commune de Katuba par un contrôle à base de filtre actif. Un total de sept transformateurs a été pris en compte et autour de chaque transformateur, un échantillon de 10 parcelles a été retenu de manière aléatoire. Deux appareils ont été utilisés pour mesurer le courant et la tension : un multimètre RMS et un multimètre ordinaire. Le niveau de pollution est ainsi obtenu par le rapport des valeurs de tensions et courant lues sur le multimètre RMS par celles lues sur le multimètre ordinaire. Les résultats obtenus ont montré que :

- Autour de 7 transformateurs retenus, il y a 10 ateliers électriques (postes à souder, moulins), 3 écoles, 1 centre de santé, 20 bureautiques. Le reste est constitué des maisons à usage résidentiel comportant des ampoules économiques, chargeurs de téléphones et ordinateurs…
- En considérant le seuil de 5% de distorsion harmonique en tension comme tolérable, les mesures effectuées attestent que les parcelles qui disposent des ateliers électriques, écoles, centre de santé, bureautiques et maisons résidentielles dépassent le seuil respectivement de 13, 8, 11, 10 et 8 unités. Pour ce qui est du courant, en considérant le seuil de 10% de distorsion harmonique en courant comme tolérable, il ressort des mesures effectuées que les valeurs enregistrées au niveau des ateliers électriques, écoles, centre de santé, bureautiques et maisons résidentielles dépassent le seuil respectivement de 19, 16, 13, 14 et 7 unités.
- En l'absence des filtres Actif, les simulations faites sur Matlab donnent des valeurs qui s'apparentent à

celles collectées sur le terrain. En utilisant le filtre Actif, avec un temps t=2 secondes, qu'au niveau du transformateur (en amont de l'utilisation), le taux de distorsion harmonique qui était de 37,63 %, a été ramené à 6,43 % après compensation. De même pour la tension, le taux qui était de 26,60 % a été réduit à 0,56 %.

Nos résultats soulignent que lorsque le filtre actif est mis en fonction, le courant et la tension de source récupèrent aisément leurs allures sinusoïdales, suggérant qu'il a généré un courant qui suit bien sa référence. Cela implique le bon fonctionnement, l'efficacité, la robustesse du filtre actif et confirme ainsi sa bonne réponse dynamique.

Innovations énergétiques, activités génératrices de revenus des femmes et développement inclusif durable au Bénin

MODIBO KARIM Talata Souleymane
Laboratoire d'Anthropologie Appliquée et d'Education au Développement Durable (LAAEDD).
Univ. d'Abomey-Calavi Bénin

SEKO OROU Baké Marie Thérèse
Laboratoire d'Anthropologie Appliquée et d'Education au Développement Durable (LAAEDD).
Univ. d'Abomey-Calavi Bénin

Monique OUASSA KOUARO
Laboratoire d'Anthropologie Appliquée et d'Education au Développement Durable (LAAEDD).
Univ. d'Abomey-Calavi Bénin

TASSO Boni Florent
Laboratoire d'Anthropologie Appliquée et d'Education au Développement Durable (LAAEDD).
Univ. d'Abomey-Calavi Bénin

Les innovations introduites dans le secteur énergétique constituent un des leviers pour la vitalité de diverses activités génératrice de revenus des femmes et pour relancer la question du développement inclusif au Bénin. Cette présentation a pour objectif d'analyser les innovations énergétiques au sein des activités génératrices de revenus des femmes capables de participer au bien-être économique et social des communautés béninoises.

Elle s'effectue dans une approche mixte. Les données secondaires ont été recueillies à travers une recherche documentaire. Quant aux données primaires, elles ont été collectées à l'aide des entretiens par questionnaire et avec guides semi-structurés auprès des promoteurs des énergies renouvelables, des femmes entrepreneuses des communes de Cotonou et de Parakou. Des entretiens approfondis et des discussions de groupes ont été menés auprès d'un échantillon d'acteurs retenus à choix raisonné. L'analyse du contenu, le logiciel R ont été mis en avant pour l'analyse des matériaux.

Cette recherche a permis de faire un état des lieux des différentes innovations énergétiques au Bénin avec une particularité sur les villes de Cotonou et Parakou. Il ressort des travaux de terrain, que l'accès à l'énergie est non seulement un fait pour le développement du Bénin, mais surtout impacte le développement des activités génératrices de revenus des femmes. Enfin, l'efficacité énergétique a été évoquée dans le sens qu'elle permet à coup sûr l'autonomisation des femmes et le développement inclusif durable au Bénin.

Optimization of biogas production from cassava peel by Response Surface Methodology

Nkodi Mananga Timothée
Faculty of Oil, Gas and New Energies
Unikin, Kinshasa, RDC

Cassava is the most produced root in the world. Globally, the five largest cassava producing nations are Nigeria (33.4 Mt in 2003), Thailand, Indonesia, Brazil and Democratic Republic of Congo (DRC) (Dunstan et al., 2017). In sub-

Saharan Africa, cassava is one of the main source of carbohydrates of people.

Whatever cassava tubers uses, peeling is the most stage where 1Kg of cassava loose 1/3 of it mass, especially the peelings. They are abandoned on site and constitutes an enhanced risk of environment pollution descreasing soil fertility. There is a need to value peels by producing biogas as fuel.

Biogas production from cassava peels mixed with some animal manure showed that the yield depended on the loading rate and the type of animal manure (Adelekan and Bamgboye, 2009). When mixed peels with urea at various concentrations, Nkodi et al.(2016) obtained the highest yield (80.79 L/KgMS) at 0.01% then that generated form the blend of cassava with animal manure. This was due to the three factors: loading rate, particle size and urea concentration, which were all significant ($p<0.05$) (Nkodi et al., 2020).

The aim of this work is to find the optimal conditions for producing biogas from cassava peels mixed with urea by using the central composite design methodology with three factors: Loading Rate (OLR), Inoculum-Substrate ratio (ISR) and urea concentration (UC). By using 1L diigester capacity the following optimal conditions were found: OLR:14.848%, ISR=0.378 and UC=0.020% with a maximum yield of 3843.676mL.

Evaluation of Napier Grass for Bioethanol Production for Africa through a Fermentation Process

Lorna Omuodo,
E-Moto Limited Kenya

Abstract

Ethanol is one of the widely used liquid biofuels in the world. Its uses as Energy fuel is varied: transport fuel, domestic cook-fuel, heating fuel and power production. The move from sugar-based production into the second-generation, lignocellulosic-based production has been of interest due to an abundance of these non-edible raw materials. E-Moto has been interested in the use of Napier grass (Pennisetum purpureum Schumach) K1 O1 varieties, a common fodder in tropical East African regions and is considered an energy crop, for ethanol production. Grows well in Marginal lands and

In our study we aim to evaluate the ethanol production potential from the grass and to suggest a production process based on the results obtained from the study.

Pre-treatments of the grass by alkali, dilute acid, and their combination prepared the grass for further hydrolysis by commercial cellulase. Separate hydrolysis and fermentation (SHF), and simultaneous saccharification and fermentation (SSF) techniques were investigated in ethanol production using Saccharomyces cerevisiae and Scheffersomyces shehatae, a xylose-fermenting yeast.

Pre-treating 15% w/v Napier grass with 1.99 M NaOH at 95.7 °C for 116 min was the best condition to prepare the grass for further enzymatic hydrolysis using the enzyme dosage of 40 Filter Paper Unit (FPU)/g for 117 h. Fermentation of enzymatic hydrolysate by S. cerevisiae via SHF resulted in the best ethanol production of 187.4 g/kg of Napier grass at 44.7 g/L ethanol concentration. The results indicated that Napier grass is a promising lignocellulosic raw material that could serve a fermentation with high ethanol concentration.

Étude de la dynamique de conversion thermo-électrique d’un groupe électrogène à base de moteur Stirling pour la production d’énergie électrique en milieu rural

V. Zogbochi
EPAC, University of Abomey-Calavi; Benin

P.K Chetangny
EPAC, University of Abomey-Calavi; Benin

D. Chamagne
FEMTO-ST - UMR CNRS 6174, University of Bourgogne Belfort, Franche-Comté, France

S. Houndedako
EPAC, University of Abomey-Calavi; Benin

G. Barbier
Laboratoire de Physique et Mécanique Textiles (LPMT), Université de Haute Alsace, Mulhouse, France

A. Vianou
EPAC, University of Abomey-Calavi; Benin

In 2020, Benin has an electricity access rate of 33.42% distributed as follows: 60.35% in urban areas against 8.78% in rural areas. Faced with this disparity, several projects aimed at extending the electricity network or setting up off-grid electrification systems (OGES) are underway. Most OGES projects are based on solar photovoltaic (without storage) which remains unavailable in the evenings when it is most in demand or if it must overcome this constraint and include storage, its cost exceeds the stock market of the target populations. At the same time, final energy consumption in Benin is dominated by biomass in the form of n into charcoal has a yield of less than 15% efficiency. This implies a huge thermal rejection both during processing and during the use of coal in households. Among the processes allowing the transformation of heat into electricity, the Stirling engine is among the best choices since it is adaptable to almost all thermal sources. This is because the Stirling engine is an external combustion and closed-cycle working fluid engine that receives heat to produce mechanical movement. The fluid is a gas (air, hydrogen, helium or nitrogen) subjected to a cycle comprising four phases: isochoric heating, isothermal expansion, isochoric cooling, and isothermal compression. This engine can use multiple hot sources coming either from the sun, underground, household or agricultural waste, industrial thermal waste, etc. The heat coming from outside, it is possible, by using non-fossil fuels, to supply it in a less polluting way than in many thermal engines where combustion is imperfect. Noise pollution is very low due to the absence of explosion systems such as in internal combustion engines. The lack of internal chemical reaction in the machine and the lack of material exchange with the environment make the Stirling engine an easy to maintain engine that lasts a long time. In addition, the Stirling cycle is reversible. It can work just as well as a motor when supplied with heat or as a refrigerator or heat pump when operated mechanically.

Our goal is to study a Stirling engine-electric generator assembly to make a compact group that can be moved like a handbag and can be used anywhere. The combination of kinetic and thermodynamic methods for a light group of 34 kg shows us that by adjusting certain heat exchange parameters, we can obtain a maximum electric power of 2500W with an overall efficiency of 38%.

Design study of a gasification reactor for manufacturing and experimentation in West Africa

Laetitia Zoungrana
Institute of Mechanics Materials and Civil Engineering,
Université Catholique de Louvain, Louvain-la-Neuve, Belgium
Laboratoire Energies Renouvelables et Efficacité Energétique,
2iE Ouagadougou , Burkina Faso

West Africa has a large potential of biomass as a source of renewable energy. One of the promising ways to valorise biomass is through gasification that allows the production of heat and electricity. This study introduces the design and the experimentation of a gasification reactor. A design methodology based on the conceptual approach proposed by Cross was adopted. This approach leads in several steps to a rational design choice based on the evaluation of different solutions. In this study, nine reactors types have been compared to select the design that best suits the defined objectives such as a local manufacturing, a safe operation and a correct gas quality. The reactor types are distinguished by the different modes of fuel supply, the methods to introduce the gasification agent and the type of bed. From this design study, a semi-batch, fixed bed reactor with air aspiration appears the most suitable to achieve the objectives. To refine the design, some technological options such as the heat recovery from the reactor walls have been studied by simulation with the Ansys Fluent software. Based on the final design, the gasifier has been dimensioned and manufactured in Burkina Faso with the help of local craftsmen. The gasifier characteristics were described for an optimal operation in a small scale industrial unit with a representative scenario that can be made of a gasifier. The average biomass consumption has been chosen at 20 kg/h and the specific gasification rate is 100 kg/m2/h while the average air flow is estimated at 30 kg/h. The usefulness of this gasifier has been defined for a small industrial rice husking unit. For an economic usability, the platform has an energy autonomy that makes it more competitive than a system powered by the electricity grid. Thus, the produced syngas is used as fuel in an engine coupled to an alternator in order to produce electricity. This electricity allows to run the huller that husks the paddy rice producing rice husk as residues and the rice husk is used in the gasifier to generate the syngas. The heat from the cooling system and the exhaust of the engine could be recovered to reduce the thermal energy needed to parboil the rice. The design study, the manufacture and the experimental results demonstrate the feasibility of a local technology for a safe and efficient gasification of biomass.

EU-Africa Science, Technology and Innovation Cooperation: Perspective

Philippe Schild
Directorate D Clean Planet,
DG Research and Innovation,
European Commission,

Science, technology and innovation (STI) cooperation between the European Union (EU) and Africa has been enhanced a decade ago with the creation of the EU-Africa High Level Policy Dialogue (HLPD) on science, technology and innovation at the 2nd EU-Africa Summit in Tripoli in 2010.

The HLPD aims to establish long term jointly funded and co-owned research and innovation actions. It is implemented through the creation of partnerships formally agreed between its members.

The first one was on Food and Nutrition Security and Sustainable Agriculture (FNSSA), but the second was on energy and climate change. At the EU-Africa joint Summit of Abidjan in 2017, the Climate Change and Sustainable Energy (CCSE) partnership was established. The CCSE partnership is based on a jointly agreed roadmap covering actions on climate change, on renewable energy and on energy efficiency.

The EU initiated already an action on energy efficiency in urban areas in Africa and a second through a joint programme of activities in the field of renewable energy technologies. They are being implemented through Horizon 2020, the EU Research and Innovation framework programme.

The European Green Deal launched in November 2019 has set as one of its priority Africa cooperation. Research collaboration is an important element of the new European Commission communication "Towards a Comprehensive Strategy with Africa".

The new EU Research and Innovation framework programme, Horizon Europe, is starting in January 2021 with its first work programmes being developed now. Those three new initiatives will offer new opportunities for collaboration.

Close-by yet inaccessible: Urban poor communities and modern energy conundrum in Africa

Emmanuel Kofi ACKOM
Dr., Ghana

In this paper, experience based on over 8 years of work on lack of modern energy for sustainable development especially focused on urban and peri-urban communities in Africa is presented. The paper will focus on the mechanisms employed by the researcher, the extent to which, and how, his work with collaborators in the continent has been able to influence change in climate-friendly energy policies and energy planning in cities in the participating African countries. This was achieved by working with key stakeholders, government departments, municipal authorities, scholars and facilitating a South-South knowledge network.

Over half of today's population, representing 4.3 billion people live in urban communities globally. Urbanization is increasing at an alarming rate, with 70% of the world's population projected to dwell in cities by 2030. The urban growth phenomenon in developing countries is driven in part by increased rural to urban migration. Due to a complex array of factors, over one billion urban dwellers are currently without adequate access to basic services, globally. This means approximately 1 in every 3 urban dwellers the world does not have access to modern energy services. Thus, energy poverty is no longer a challenge in rural communities alone, but it has also become a key urban problem in developing nations including many African countries. Several studies have underscored that access to modern energy services - Sustainable Development Goal (SDG) 7 - is an essential enabler of development and socio-economic empowerment of communities with a multiplier effect towards achieving key SDGs. This multi-country study was conducted globally including three African cities, namely in Dakar (Senegal), Nairobi (Kenya) and Cape Town (South Africa) over 8-year period. The objective of the study was:

- to understand the barriers (both supply and demand-side) hindering access to electrification in urban poor communities;
- an analysis of existing energy policy reforms and whether they sufficiently address the challenges facing urban poor;
- an assessment of how policy processes could be improved to promote better access to cleaner energy services for poverty alleviation and productive uses of energy.

Data collection using common indicators was undertaken across all the countries in the field study. Additionally, a policy dialogue Panel (PDP), which was a structured mechanism for engaging our researchers, policymakers, local representatives from the respective communities along the research value chain was established. Based on findings from the study across the countries; it was evident that the lack of tenure; policy conflicts; weak alignment between energy policies and urban planning; the high upfront cost of electricity connection and tariff structures; the high cost of energy-efficient appliances and the inability of the poor to benefit from subsidized tariff structures were common. An interesting observation was the increased uptake of the research findings in policy reformulations, due in part to the PDP we employed in this study. Possible recommendations include innovations in PDP, financing, social inclusion, policy reformulation, international cooperation and peer-to peer knowledge sharing among urban poor communities.

Sustainable Strategy for Transportation Fuels in West-Africa: A 2050 Prospective Assessment

Edgard Gnansounou
Ecole Polytechnique Fédérale de Lausanne EPFL
ENAC IIC GR-GN, Lausanne

West African countries depend on fossil fuels for the transportation of goods and passengers. While in the short to medium term, this situation cannot significantly change, it is worthwhile to develop a long term vision on wide scale introduction of renewables into the energy matrix of this subsector. Transportation sector is one of the biggest energy consumer worldwide and it is fueled almost exclusively by petroleum products. According to the World Energy Balances 2020, the share of the transportation sector in the total final oil consumption in 2018 was about 65% including 49% for road transportation.

Depending on the scenarios, the share of the transportation subsector in the world final energy consumption in 2040 would be in the range of 27.5 – 28.5%. Because of its energy profile, transportation subsector is one of the main CO2 emitters in the energy sector and finding strategies aiming at improving its environmental performance is challenging. Due to lack of statistics, it is not easy to undertake a precise diagnostic in the case of West African countries. However, the weak development of electrified railways and modern renewable energy would suggest that dependency on oil is higher compared to the world case. Factors such as high demographic growth, potential of economic growth and free movement of goods and people within the Economic Community of the West Africa States (ECOWAS) can enhance the growth of Transportation subsector w in the next decades in West Africa. Hence, the concern regarding the non-diversity of energy in this subsector and its dependence on fossil fuels in West Africa is of utmost importance.

This prospective study focuses on the use of biomass to produce transportation fuels such as synthetic natural gas, second generation bioethanol and electricity under a sustainable scenario in West Africa in 2050. The aim of this work was to evaluate the feasibility of producing such biofuels using agricultural residues as feedstock in the studied area. The potential of biomass from ten agricultural residues was estimated in R environment using FAO data. Options were analyzed in order to generate portfolios of transportation fuels based on energy indicators, biomass availability taking into account the requirements to leave part of the residues for the regeneration of the soils. Scenarios of technological progress are considered as well. The optimal allocation among the technology options was found out for each country and the sub-region as a whole, based on a multi-objective objective optimization.

Extracting Maximum Value from trees

Bruce Sithole
Prof. Chief Scientist and Director,
Biorefinery Industry Development Facility,
Council for Scientific & Industrial Research, Durban, South Africa.

College of Agriculture & Engineering Sciences
University of KwaZulu-Natal, Durban, South Africa

Depletion of fossil fuels and the environmental concerns related to their use, together with increased energy demands and the need for cleaner production technologies across all industries is providing strong impetus in the search for alternative and renewable raw material resources. Our fossil driven economy has resulted in many challenges for the earth including increased greenhouse gas emissions, climate change and global warming. To promote sustainable growth with minimal environmental impact, alternate and renewable resources need to become an important part of the feedstock raw material for many of our industries. Currently the Forestry, Timber, Pulp and Paper (FTPP) sector is wasteful and has limited products. For example, the sector extracts only about 47% value from trees with the majority of trees being lost as waste. At the same time, there is ever-increasing pressure on the industry to make changes, improvements and/or adaptations to their processes in order to achieve cleaner production technologies that are more environmentally friendly. The disposal of their waste by-products in an economically and environmentally acceptable manner is another critical issue facing the industry. This is mainly due to challenges in locating disposal works and complying with environmental requirements imposed by waste management and disposal regulations. For example, sawmills produce large volumes of sawdust and other tree trimmings such as bark, leaves and branches. Pulp and paper mills, in addition to the aforementioned waste streams, also generate large quantities of process waste by-products in the form of sludge, dregs and fly ash. These by-products are traditionally stock-piled on site, landfilled, or burned. However, according to environmental regulations, these practices are being curtailed as they are environmental hazards that generate greenhouse gases and can lead to possible leaching of toxic chemicals into surrounding ground and water sources. In the case of landfilling as a means of waste disposal, significant costs are incurred by industry for transporting waste to landfill sites, maintaining landfill sites, and establishing new landfill sites once the previous ones are full. The problem is further compounded by the fact that suitable land for landfilling in relatively close proximity to where the waste is generated is limited. Opportunely, the waste streams generated by the forestry industry sectors are composed of potentially high value products and finding alternative and innovative uses for these industry waste streams and diverting them from landfill will transform the face of the industries, both economically and environmentally. This can be achieved via biorefinery technologies. The overall objective of biorefinery research and development is therefore to contribute to the evolution of FTPP mills into forest biorefineries through innovative biorefinery technologies, and in so doing, revitalise industrial development opportunities within this renewable biomass processing sector, whilst at the same time mitigating some of its environmental impacts. This will ensure that the industry stays abreast of new environmental and technological developments in order to remain internationally competitive and economically sustainable. Increased revenue streams from the production of new bio-materials and chemicals would ensure preservation of infrastructure, jobs, supply chains and permits, whilst at the same time helping countries minimise their energy problems and environmental impacts. The R&D on biorefinery technologies directly addresses some of the challenges associated with transitioning to a green economy and proper implementation of the technologies can result well over 90% tree utilisation.

Energy storage landscape in South Africa and the rest of Africa

Kenneth I. Ozoemena
Professor , School of Chemistry,
University of the Witwatersrand,
Johannesburg, South Africa

As the 4th Industrial Revolution falls upon us, the main challenge to the widespread deployment of the ever-increasing technological advances (consumer electronics, autonomous vehicles, electric vehicles, etc) will be energy storage and conversion systems that will power them. Also, electrochemical energy technologies (EETs) such as advanced batteries, supercapacitors and fuel cells, are critical to unlocking the potential of green transport such as electric vehicles, and the utilization of renewable energy sources (solar and wind) as well as the realization of energy efficiency technologies.

Africa is richly endowed with all the energy resources to harness and store its abundant renewables (solar and wind) yet suffers from energy poverty. Off-grid storage is most critical (e.g., solar-plus-battery systems in rural Sub-Saharan Africa) if one considers that more than 70% of the 1.2 billion of Africans (> 840 million people) do not have access to electricity.

There are different energy storage opportunities available to Africa: 1) Electrochemical (e.g., secondary batteries, flow batteries); (2) Chemical (e.g., hydrogen); (3) Electrical (e.g., supercapacitors); (4) Thermal (e.g., heat storage); (5) Thermochemical (e.g., solar hydrogen); and (6) Mechanical (e.g., pumped hydro storage). African is described as the “sun continent” due to its huge available solar energy (~ 60,000,000 TWh/year) which is about 40% of the global total. Africa’s huge wealth in solar energy and the global quest to curb the disastrous climate change makes it necessary for the continent to lead in sustainable energy technologies.

This presentation will discuss some of the research activities in Africa that explore some African’s abundant solar energy and solid minerals for the development of affordable and safe-to-use EETs such as lithium-ion batteries (LiBs), sodium-ion batteries (SIBs), supercapacitors and fuel cells for the realization of SPB technologies.

The Energy Return on Investment (EROI) and the accessibility of renewable energy

Hervé Jeanmart & Elise Dupont
Institute of Mechanics, Materials, and Civil engineering,
Université catholique de Louvain,
Louvain-la-Neuve, Belgium

Energy is a main driver of all human activities. Its use is well correlated with the economic activity measured by the world gross domestic product. Energy consumption is ever growing due to population and economic affluence increases. This energy being mainly fossil, it induces climate change. To reduce its impact, the world must switch from a fossil fuel-based to a low-carbon economy. The transition is complex and involves many dimensions and challenges, including energy efficiency, electrification and storage, green growth vs degrowth, etc. One important dimension is the availability of renewable energy, i.e. the amount of renewable energy that can be harvested worldwide. Studies show that solar and wind energy have the highest potentials, followed by biomass . Moreover, these potentials are much higher than the actual needs. However, to be useful for the human beings, renewable energy must be effectively harvested and delivered in consumption centres. Taking physical limits into account largely reduces these potentials and leads to the definition of the accessibility of the energy, i.e. the amount of energy that can be effectively, in other words economically, harvested by our societies.

To assess the accessibility, a metric, measuring the cost, must be used. Usually, the economic cost is considered, but it might be biased and distorted. In this paper, the Energy Return on Investment (EROI) is preferred to study the accessibility of both wind and solar energy . The EROI is defined as the ratio between the energy produced during the lifetime of a facility and all the energy required to build, operate, maintain and decommission it. It has been shown that the EROI is a decreasing function of the installed capacity. It is also shown that while solar energy has a lower EROI, it has a much larger potential than wind energy. Linking renewable energy and the EROI is critical for affluent societies that are used to consume fossil energy with a high EROI. Indeed, renewable energies have lower EROIs that fossil fuels due to their higher capital intensity. On the contrary, it is an opportunity for less affluent societies that could benefit greatly from an energy system based on modern renewables. This is addressed by linking the EROI of the energy system and the growth in the economy.

The X-techLab initiative in Benin: a regional platform dedicated to capacity building in science education

Thierry d’almeida

Polyanions phosphate and phosphite materials for Li-Ion Batteries: Moroccan resources valorization

Fouzia Cherkaoui El Moursli
MANAPSE, Mohammed Vth University
Rabat, Morocco

Batteries with higher energy density, longer life and higher safety have led to identify and develop alternative materials and technologies that can meet increasingly stringent requirements. Among interesting materials, polyanion compounds such as silicates (SiO44−), borates (BO33−), phosphates (PO43−) and pyrophosphates (P2O74−) are being actively investigated. They have the advantage of being very stable thanks to their open frameworks that provide long-term structural stability and higher safety when used as cathodes, compared to layered oxide compounds known to dissolve easily in organic electrolytes. Polyanion compounds of metals also allow, obtaining higher voltages vs. Li+/Li resulting in high energy densities. Finally, due to their chemical nature various structures and compositions can be built offering a large spectrum of applications within the battery. Indeed, polyanion compounds cannot only be used as cathodes but also as anodes or solid electrolytes. Phosphates and their derivatives attract particularly our attention because they present the most important natural resource of Morocco to be valorized. As example phosphite (HPIIIO3)2- based compounds received little or no attention. Replacing metal phosphates Mx[PO4]y by metal phosphites Mx[HPO3]z can be of big interest, thanks to the various new structures that can be obtained. In metal phosphate structures, phosphate tetrahedral [PO4]3− have four connections with the metal where, phosphite pseudo pyramids [HPO3]2− have only three connections making a greater open framework and large tunnel structures allowing a better cation conduction. Finally, phosphites polyanions have also shown their ability to electrochemically stabilize electrolytes. In this presentation, our last findings (phosphites synthesized for the first time) at MANAPSE laboratory (MAtériaux et Nanomatériaux pour le Photovoltaïque et le Stockage de l'Énergie) and applications of phosphites (anodes, interface layers…) will be presented.

EU CBRN Centres of Excellence- Strengthening preparedness on CBRN incidents in Africa

Alina Iatan
Scientific and Technical Project Manager
European Commission Joint Research Centre, EURATOM

The European Union Chemical Biological Radiological and Nuclear Risk Mitigation Centres of Excellence Initiative (or EU CBRN CoE) was launched in 2010 in response to the need to strengthen the institutional capacity of countries outside the European Union to mitigate CBRN risks (intentionally, accidentally or naturally created). Through the EU Neighbourhood, Development and International Cooperation Instrument (NDICI), the initiative funds regional projects in the area of CBRN risk prevention, preparedness and response. The European Commission works directly with 62 Partner countries that voluntarily joined the initiative to develop a deeper understanding of individual country needs and conduct a regional analysis in the field of CBRN.

The Joint Research Centre (JRC) contributes to the implementation of the CoE Initiative by providing scientific and technical assistance for the assessment of the needs of partner countries in terms of capabilities in CBRN emergency preparedness and response through the evaluation of projects' implementation and outcome.

The COE initiative encompasses on a worldwide network of local experts and collaborating regional and international partners such as UN Agencies (UNICRI, WHO). The activities are developed in partnership with partner countries in view of encouraging local ownership of CBRN action plans and strengthening national legal frameworks on CBRN risk mitigation. The analysis of the capacities and gaps identified helps defining the CoE projects that bring an added value to the individual countries or the eight regions. Proof to it, 27 Partner countries have prepared a National Action Plan on CBRN risk mitigation which is subsequently endorsed by national authorities as part of their national law.

Through this programme, the EU has been supporting the countries to enhance their CBRN capabilities though the provision of CBRN equipment and transfer of CBRN knowledge and skills. This is done through the implementation of EU funded projects that include training of first responders, addressing gaps in national legislative frameworks on CBRN, tackling the illicit trafficking of CBRN materials and the planning of post incident recovery measures, among many other topics. Some of the reference projects in Africa:

P60 – Support to the Eastern and Central Africa in Nuclear Security focuses on nuclear security. The overall long-term objective of this project is to strengthen and harmonize the nuclear regulatory frameworks in the participating countries, to enhance their national nuclear safety and nuclear security regimes in support of the fulfilment of national obligations under international instruments (IAEA NSSC, in particular).

P69- High risk chemical facilities and risk mitigation in the African Atlantic Façade Region (INSTASUR) which aims at developing capacities for the efficient management of chemical risks in the AAF region to ensure the prevention of major risks (accidents and/or pollution) in and outside plants containing chemicals and to respond quickly and adequately in the event of incidents.

P71-Safer and more secure transportation of dangerous goods by road and rail (SECTRANS AAF). Transportation of dangerous goods (TDG) covers three product families: liquid petroleum products (75%), miscellaneous chemicals (20%) and gases (5%). While this type of transportation is essential, it is critical to manage associated risks. Project 71, implemented by EU and international experts with sound knowledge in dangerous goods and the implementation of relevant SoPs, addresses the entire chain of safety, from regulation to intervention, and covers in particular driving and other safety issues during transportation, loading/unloading operations, as well as operational procedures in case of accident.

Long-Term Joint European Union - African Union Research and Inovation Partership on Renewable Energy

BUKASA KAMPATA Niclette
LEAP-RE | Europe-Africa Partnership for Renewable Energy
DSI, Pretoria, South Africa

NTSHONGWANA Tinyiko
Rhodes University
Pretoria, South-Africa

COLOMBO Emanuela
Politecnico di Milano, Department of Energy, Italy

LEVEQUE Léonard
LEAP-RE | Europe-Africa Partnership for Renewable Energy
LGI, Marseille, France

PLATH Melissa
Finnish University Partnership for International Development (UniPID), Helsinki, Finland

WAMBUGU Anne
Strathmore University, Strathmore Energy Research Centre, Kenya

The ambition of LEAP-RE is to establish a long-lasting EU-AU research and innovation partnership on renewable energy. One of the most effective ways to support the transformative path toward sustainable, affordable and accessible energy is the promotion of joint research and innovation efforts. Impact will be sought by creating a framework, methodology, and cooperation model. The aim is to reduce fragmentation by aligning existing bilateral and multilateral frameworks. LEAP-RE establishes and jointly implements research, innovation, and capacity-building activities that respond to Multi-Annual Roadmaps (MARs), representing the main topics related to renewable energies development and described in terms of social challenges, research scope, and expected output, outcome, and impact. These six MARs serve as the basis for the LEAP-RE Joint Call 2021 and for the 8 projects undertaken in Pillar 2:

- Mapping joint research and innovation actions for future RES development
- End-of-life and second-life management and environmental impact of RE components
- Smart stand-alone systems (SAS)
- Smart grid (different scale) for off grid application
- Processes and appliances for productive uses (PRODUSE)
- Innovative solutions for priority domestic uses (clean cooking and cold chain)

To match its ambitious objectives defined above, LEAP-RE is conceived as a programme, rather than an individual project. This programme is built on three pillars with their own conceptual approach:

Pillar 1: Organise and demonstrate joint programming and joint funding, by pooling national and regional agencies along with top-up EC funding from this grant. This first pillar relies on the implementation of open calls for R&I and capacity-building proposals, funded by national / regional agencies, and monitoring of execution and impact ;

Pillar 2: Coordinate, cluster and monitor impact of individual projects chosen to address MAR objectives and capacity-building projects with substantial co-funding from the research institutions, implemented by consortium members ;

Pillar 3: Build a community, strategy, organisation, methodological assets and tools to set the foundations of a long-lasting AU-EU partnership to address the post-2025 challenges and policy priorities. It mainly consists in programme management and all strategic activities to strengthen the community, maximise impact and build the future long-term AU-EU partnership.

LEAP-RE opted for a large-scale, inclusive consortium of 83 partners from 33 countries to ensure a broad thematic, geographical and stakeholder coverage, and to demonstrate the feasibility of the collaboration and build trust in view of a long-term partnership addressing the post-2025 period.

Energie nucléaire pour l’Afrique et par l’Afrique : rêve ou réalité - The development of Small Modular Reactor (SMRs) for emerging nuclear countries in Africa

Hamid Aït Abderrahim
Prof., Deputy Director-General International Affairs SCK•CEN & UCLouvain
and Prof. Peter Baeten, SCK•CEN & VUB Kernenergie

The renewed interest in nuclear power in Africa driven by a rapidly growing energy demand, persistent concerns over climate change and dependence on overseas supplies of fossil fuels has increased the prospects of considering this option in national energy strategies to ensure access to affordable energy for sustainable development. Many African countries have begun revisiting the nuclear option over recent years with a view to establishing long-term sustainable energy supplies.

A first prerequisite is the development of national and regional planning for nuclear power development. Secondly, adequate legal and nuclear safety and security measures and infrastructures need to be installed. Thirdly, government leadership is necessary for the initial programme development, while continued government support is required throughout the life of the programme. In addition, funding and financing during the initial programme development are necessary and critical. Moreover, in Africa the compatibility and integration in the electrical grid should also be considered as an important infrastructure consideration. Last, but not least, one needs to address the human resource requirements of a nuclear power program.

Based on the previous considerations it is clear that large NPP's of 1000 MWe and beyond are not that well suited to respond to the demand. Small Modular Reactors with a typical power of maximum 300 MWe show the following benefits. First of all, from the point of view of grid considerations, SMR's are better suited to respond to: (1) electrical grids with limited capacity; (2) remote areas requiring smaller localized power plants to avoid long and expensive transmission lines; (3) geographically dispersed small- and mid- size urban plants; (4) incremental production capacity.

Secondly, SMR's require a smaller capital investment cost and have the potential to reduce the cost uncertainties and construction timeframes associated with conventional NPPs. Because of the smaller size, they could even be used in remote African locations.

Large NPP's as well as SMR's require decay heat removal after shutdown. This represents 6% of the nominal power; SMR's with lower power can be designed more easily for passive decay heat removal.

Besides electricity production, SMR's could also address the need for water desalinisation and industrial heat cogeneration.

Today, several concepts based on the current Light Water Reactor technology are becoming ready for industrial deployment. However, these concepts based on water as a coolant will generate the same type of long-lived spent fuel as we encounter today in the Western world. To go also for a more sustainable solution of nuclear energy production with SMR's in Africa, a shift towards so-called fast neutron SMR's, not based on water as a coolant, is recommended. This offer to have very long refuelling times up to 10 to 15 years, resulting in only 2 or 3 reloads over its lifetime. All these aspects and corresponding technologies will be covered.

How Innovation and Capacity Building will Disrupt the Sustainable Energy Space and Aid Climate Action

Glory Oguegbu
Renewable Energy Technology Training Institute (RETTI)
Nigeria

Lack of electricity and constant power outages in Africa has hindered economic growth and development especially through the death of small businesses. Climate change impacts on the other hand had affected crop yield, lead to diseases in northern Nigeria and flooding has swallowed arable lands in the south.

According to the international energy agency 93 million Nigerians lack access to electricity. But investments into the sector especially in Africa has seen positive light as global investment for the development of solar power increased significantly and hit a peak of 330 billion dollars in 2015 (IRENA). However, this investment have revealed a new problem - the lack of competent and skilled workforce or entrepreneurs to leverage the investment and promote clean electricity to communities that are off the grid and reduce carbon emission through the process.

Human capacity training, with content made possible through scientific resource, is therefore paramount if we must promote renewable electricity, conserve energy, build bridges that will lead to energy sustainability in transport, residential and businesses sectors, combat climate change, and create the policies that will enable this transition. Most importantly renewable energy for electricity is an area of knowledge that is somewhat new to people, therefore it must be taught across all spheres helping everyone understand how it works, its structure, the applications, opportunities and everyone's role.

This section will present the answer to the question - how do we support innovation for the clean and renewable energy sector to promote energy sustainability and combat climate change? In addition to that, the presentation will share an overview of the problem in the Nigerian context and show how human capital development can promote sustainable and clean energy, aid the development of energy systems, policies and ultimately contribute to economic growth and development.

The section will share the case study of how - The Renewable Energy Technology Training Institute (RETTI) has supported research, innovation and education for the renewable energy sector taking a closer look how training young people from the slum community of Makoko without access to electricity enabled up to 757 households access to renewable clean electricity.

Distance learning in hydraulics : MOOCs and beyond

Sandra Soares-Frazão
Institute of Mechanics, Materials and Civil Engineering, Université catholique de Louvain, Belgique

Adermus Joseph
Faculté d'Agronomie et de Médecine Vétérinaire, Université d'Etat d'Haïti, Haïti

Nyankona Gonomy
Faculté d'Agronomie et de Médecine Vétérinaire, Université d'Etat d'Haïti, Haïti

Yves Zech
Institute of Mechanics, Materials and Civil Engineering, Université catholique de Louvain, Belgique

Stephen Louis
Faculté d'Agronomie et de Médecine Vétérinaire, Université d'Etat d'Haïti, Haïti

Within the framework of the RESCIF network (www.rescif.net), several MOOCs have emerged since the initial impulse given by EPFL in 2012 who was leading the network at that time. Among these, the "Hydraulique Fluviale" MOOC (course about fluvial hydraulics, in French) was developed on the EdX platform in a collaborative way by teachers from UCLouvain (Belgium), the State University of Haiti (UEH) and EPFL (Switzerland). This MOOC is divided into two parts lasting four weeks each. The first part "Hydraulique Fluviale 11" focuses on free surface flows in canals and natural rivers, including some elements of bathymetric measurements essential for the flow calculations, and gives an introduction to the use of numerical simulation software. The second part "Hydraulique Fluviale 22" concerns the transport of sediments in natural rivers and irrigation canals. These courses include many examples issued from the author's experience, including several Haitian sites.

During the first editions of these courses, the formula for learners consisted of a registration to follow the course at fixed dates, while teachers were available online to answer questions, lead debates, and remind the learners of the different deadlines. In addition to these entirely remote editions, a one-week face-to-face course experience based on the MOOC was conducted with the Haitian partners. The students had all followed the four-week MOOC course (part 1), and the one-week face-to-face course at UEH was organized just before taking the final MOOC exam. It was an opportunity for the students to go deeper into the course, to ask questions, and to review various aspects that were less understood. At the end of this week, the students took the final exam of the MOOC in class. One conclusion from this experience was that the students preparation by watching videos of the different lessons had been really effective and had significantly increased their motivation.

At present, after a few years of experience with the MOOCs, we are observing an evolution in the way in which learners consider the courses. This evolution has been further accelerated by the COVID crisis which has changed traditional education for many students, learners and teachers into distance education, using MOOCs or lesson podcasts. It appears that the initial MOOC formula open as a regular course over a fixed period of time no longer meets the expectations of learners who each have their own schedule. Significant video registrations and viewing rates were observed even outside of official opening times. Learners, from very diverse origins and backgrounds, seem more in search of tailor-made learning paths.

In this communication, we will briefly recall the evolution of the MOOCs that we have led in the field of hydraulics, and we will look at some perspectives that we believe are relevant for the future, to go beyond classical MOOCs and propose the best possible distance learning experience.

Contribution of mapping to wind power, solar photovoltaic and hydroelectric energies potential assessment from the highlands of Bitchoua (West Cameroon)

Eneckdem Tsopgni Vadel
Department of Geography,
University of Yaounde I,
Cameroun

Tchindjang Mesmin
Department of Geography,
University of Yaounde I, Cameroun

Étongué Mayer Raoul
Geography Department,
Laurentian University,
Sudbury,g, Canada

Valuing renewable energies requires the availability of data on the exploitable potential at the finest spatial scales (Denfe et al. 2011). Moreover, in underdeveloped countries like Cameroon, atlases and data on renewable energy potential are not always available (Ould Bilal et al. 2010). Thus, and wrongly, it envisages the promotion of these energies according to a postulate of spatial homogeneity, without however invoking the geographical determinants of their production (Pinker & Laszlo, 1992). It is with a view to providing support for optimal decision-making that this study aims to evaluate by showing the relevance of mapping in the analysis of renewable energy potential at the scale of the rural locality of Bitchoua. The work is based both on Geographic Information Systems (GIS), climate data from NASA Surface Meteorology and Solar Energy (SSE) from 1985 to 2018, hydrological data from the Invest-Elec project and data from field surveys in 2020. The spatial analysis, coupled with the quantitative and qualitative processing of these data, made it possible to obtain information on the direction of the winds, the distribution of wind speed frequencies (by the Weibull method), the modeling of the relief, of the slopes. , and the hydrographic network. From this arises the numerical simulation of the data in order to provide predictions of the electrical energy that may be generated. The study shows that with an average speed of 2.56m / s, the winds from Bitchoua would generate an electrical power of 974.17 W / s with a wind generator 50 m in diameter. Also, the North-North East of the locality appears to be the most suitable area for the installation of wind turbines. The analysis of the potential in photovoltaic solar energy shows that with a daily irradiation rate of approximately 5.81 kWh / m2, for an optimal daily average sunshine duration of 7 hours, it would be possible to theoretically produce over any the surface of the locality approximately 353 GWh per day. For the Small Hydroelectricity (PHE), although having only modest rivers (coveted for agro-pastoral and domestic activities), Bitchoua would have in its East-North-East part on the Mondoui river a rather significant potential. Also not far from Bitchoua, the Invest-Elect project revealed two sites on the Képéte river with hydroelectric potential. These two sites would have installed capacities of 0.22 and 5.29 MW, for approximately 0.50 and 12.76 GWh of guaranteed annual production. Thus, by mobilizing GIS in the assessment of renewable energy potential, the study proposes a decisional mapping allowing the planning and implementation of wind, solar photovoltaic and hydroelectric projects in the studied area.

Energy scenarios modeling for Africa - An Energy Partnership between North Africa and Europe

Bob van der Zwaan
TNO Energy Transition, University of Amsterdam, Faculty of Science
Johns Hopkins University (SAIS Bologna)

In this paper we investigate the prospects for the large-scale use of low-emission energy technologies in Africa. Many African countries have recently experienced substantial economic growth and aim at fulfilling much of the energy needs associated with continuing along paths of economic expansion by exploiting their large domestic potentials of renewable forms of energy. Important benefits of the abundant renewable energy resources in Africa are that they allow for stimulating economic development, increasing energy access and alleviating poverty, while simultaneously avoiding emissions of greenhouse gases. We analyse what the likely energy demand in Africa could be until 2050, and inspect multiple scenarios for the concomitant levels of greenhouse gas emissions and emission intensities.

We use the TIAM-ECN model, which enables detailed energy systems research through a technology-rich cost-minimization procedure. TIAM-ECN is a TIMES based IAM

operated at the Energy Transition department of TNO. Like with other optimization models, TIAM-ECN can be used for finding cost-minimal energy systems, at the global level as well as regionally or nationally, that meet requirements such as in terms of climate change control. For a more detailed description of TIAM-ECN we refer to our previous work (see e.g. Rösler et al., 2014; Kober et al., 2016; van der Zwaan and Dalla Longa, 2019). Models like TIAM-ECN are often maintained and operated by engineers – it is envisaged to explore opportunities to let energy engineers and environmental economists from both Europe and Africa work together so as to jointly achieve the target of clean energy development in Africa.

The results from our analysis fully support an Africa-led effort to substantially enhance the use of the continent's renewable energy potential. But they suggest that the current aim of achieving 300GW of additional renewable electricity generation capacity by 2030 is perhaps unrealistic, even given high GDP and population growth: we find figures that are close to half this level. We analyze the energy needs in Africa, which currently relies for around 90% on traditional biomass, and till little on various (renewable and non-renewable) electricity production resources. With our work – with SDG 7 as our main guiding principle – we aim at developing energy strategies in Africa in collaboration with local actors across all main sectors (residential, industrial, transport and service). Our analysis enables assessing policy instruments that can assist in the implementation of these energy strategies, and can fulfill education and training purposes, both at African universities and in policy making circles.

Among our main conclusions is that we find evidence for leap-frogging opportunities, by which renewable energy options rather than fossil fuels could constitute the cost-optimal solution to fulfil most of Africa's growing energy requirements. An important benefit of leap-frogging is that it avoids an ultimately expensive fossil fuels lock-in that would fix the carbon footprint of the continent until at least the middle of the century.

The full paper related to this presentation has been published by Elsevier: "Energy Policy 159 (2021) 112613"
Available online 5 October 2021
Timmermans' dream: An electricity and hydrogen partnership between Europe and North Africa
Bob van der Zwaan a,b,c,*, Sam Lamboo a, Francesco Dalla Longa a
a TNO, Energy Transition Department (ETS), Amsterdam, the Netherlands
b University of Amsterdam, Faculty of Science (HIMS and IAS), Amsterdam, the Netherlands
c Johns Hopkins University, School of Advanced International Studies (SAIS), Bologna, Italy

Energy Access Explorer, a dynamic geospatial information system to connect SDG 7 and sustainable development outcomes

Dimitrios Mentis
World Resource Institute's (WRI's)

To effectively expand energy access, government planners need to understand and have access to data and analytical tools that capture key attributes of the unserved and under-served populations they are trying to reach. (Today about 840 million people lack access to electricity.) Medium- to long-term energy planning tools used by planners consider spatially aggregated regions to solve complex cost-optimization problems. Although recently developed energy planning tools based on geographic information systems (GIS) focus on identifying technology and investment needs to provide access to unserved areas, these tools currently integrate limited information on demand and affordability. We need a better understanding of the needs and constraints of these new customers if we are to supply electricity in an economically sustainable manner. This paper introduces the methods and data used in Energy Access Explorer. The latter is an online, open-source, interactive platform that analyzes spatial data related to energy supply and demand and a population's unique attributes. Location specific resource availability and infrastructure data are used to indicate energy supply, and demographic data and data on the social and productive uses of electricity help visualize demand. Together, these supply and demand indicators enable more comprehensive and geographically targeted energy planning not only for energy planning institutions but also for clean energy entrepreneurs and development finance institutions and donors.

2nd Edition of the international conference on Sustainable Energy for Africa (SE4A 2021) :

FINAL REPORT

8 - 11 November 2021, Palais des congrès, Cotonou, Benin

INTRODUCTION

From 08 to 11 november 2021, the 2nd edition of the international conference « Sustainable Energy for Africa (SE4A) » took place in Cotonou, Benin. It was co-organised by the Académie Nationale des Sciences, Arts et Lettres du Bénin (ANSALB) and the Royal Academy of Oversea Sciences (RAOS) of Belgium. The theme of this conference was « Energy is crucial for achieving the Sustainable Development in Africa ». It took place in hybrid mode (in person and on line). It brought together deciders, academicians, university professors and researchers and international experts in the field of energy. These participants, about 200 (in person and on line) are coming from more than 30 countries from Africa, Europe and the Americas.

After the opening ceremony, it included 11 plenary communication sessions, a poster session, four seminars (on nuclear, solar and financing instruments and on the training of experts for Africa).

DESCRIPTION OF THE CONFERENCE SESSIONS and SEMINARS

1st Day of the International Conference SE4A (08 NOVEMBER 2021)

SESSION 1 : Opening ceremony

The 2nd edition of the international conference on Sustainable Energy for Africa (SE4A), opened on Monday, November 08, 2021 in the "blue room" of the Palais des Congrès in Cotonou. In attendance were ministerial authorities from Benin (Minister of Higher Education and Scientific Research, Minister of Energy and Water); members of the diplomatic corps (the Ambassadors of Belgium, Morocco, Egypt and the representative of the Ambassador of Niger), the President of the Network of African Science Academies (NASAC); the President of ANSALB, the Permanent Secretary of RAOS, representatives of the European Union (EU) and the African Union (AU); Academicians from Benin, Belgium and Morocco, Rectors and Vice-Rectors of the National Universities of Benin; experts, researchers and specialists in energy issues from more than 30 countries in Africa, Europe and the Americas, students in the energy sectors of public and private universities in Benin.

The opening ceremony consisted of a series of speeches. It began with words of welcome from the President of ANSALB, Academician Nazaire PADONOU. He started by thanking the Government of Benin for the facilities granted for holding this meeting. His thanks also went to RAOS; partners and sponsors, and all the Beninese and Belgian experts whose efforts and collaboration enabled to prepare the meeting. He recalled the particular health context of Covid-19 which required that the conference take place in hybrid mode. He then indicated the important role that energy plays in achieving the SDGs and the objectives of the 2063 agenda for Africa, before announcing the major themes that will be discussed during the 4 days of discussions.

After him, the Perpetual Secretary of RAOS, Philippe De Maeyer indicated that this conference was a recommendation of the 1st conference held in Brussels from October 23 to 25, 2017 at the Palais des Académies. Indeed, one of the messages delivered by way of conclusion was the organization of a follow-up edition in Africa to report on the latest developments and discuss joint actions in the energy-climate sector. He expressed his joy to see it held in an African country, Benin.

The President of the Network of African Science Academies (NASAC), Academician Norbert HOUKONNOU has shown the need to invest massively in science, technology and innovation to support the solid and sustainable inclusive development of our countries, in harmony and respect for their socio-cultural ecosystems. He underlined the availability of plural expertise at the level of the academies and scientific institutions of the countries but also at the level of the Network of African Science Academies and their partners to enlighten the public authorities and the private sector in taking science-backed decisions.

Mrs. Fadila Boughanemi representing the EU, indicated that the theme of energy is one of the priority areas of EU-AU cooperation with actions in research and innovation. The EU is therefore very attentive to the conclusions of this conference.

Along the same lines, the Ambassador of Belgium wished that the recommendations of this 2nd edition of SE4A be transmitted to the group of French-speaking ambassadors in Africa.

For the Minister of Energy, Dona Jean-Claude HOUSSOU, it is a honour and a pride to see this conference taking place in Benin. He thanked the two academies for the organization. He recalled that energy is the driver of economic and industrial development and therefore contributes to the well-being of populations. This justifies the reforms undertaken by the Beninese government (under President Patrice TALON) since 2016. These actions have made it possible to achieve an energy self-sufficiency of 60% and some ongoing projects are oriented towards renewable energies.

For the Minister of Higher Education and Scientific Research, Professor Éléonore YAYI LADEKAN "the importance of energy no longer needs to be demonstrated" and it is with this in mind that the two academies had the wise idea of initiating this conference. She expects participating experts to put in place methods for producers and consumers that ensure the sustainability of abundant renewable resources such as hydroelectricity, wind and solar energy.

SESSION 2: Energy access and socioeconomic development as primary drivers.

The second session of the day focused on: access to energy as a main driver of socio-economic development, and was moderated by Mr. Thierry d'Almeida (Benin) and Mr.Jean Snoeck (Belgium)..

The first communication entitled *"Moroccan National Energy Strategy"* was presented in person by Mrs. Rajaâ Cherkaoui El Moursli (Morocco).

Then, the communication *"International cooperation in research and innovation is a strategic priority for the EU"* was presented in videoconference from Belgium by Mrs. Fadila Boughanemi (representative of the European Union)

Third, the communication « *Renewable Energy as an enabler for socioeconomic development in Africa* » was presented in videoconference by Mr. Nopenyo Dabla (Togo.)

Finally, Mr. Mawufemo Modjinou (Ghana), representing Mr. Appolinaire Ki (Burkina Faso), presented a video conference entitled *"Improving electricity supply in West Africa: the potential of cross-border power trading"*.

In this session, renewable energy was presented as a catalyst for socio-economic development in Africa. The example of Moroccan national energy strategies was developed. The energy issue requires international cooperation in research and innovation and for Mrs. Fadila Boughanemi this is a strategic priority for the EU in its cooperation with the AU.

The last presentation discussed the electricity supply in West Africa by showing the axes of possible improvements based on the potential of cross-border electricity exchanges.

During the question-and-answer phase, the discussions focused on: – the contribution of thermal solar in the total energy production in Morocco – the possibility of using Niger's uranium for electrical energy production in the Economic Community of West African States (ECOWAS) – the importance of training in the implementation of strategies – research funding – the current situation of cooperation through the interconnections of West African countries (WAPP) – the links between renewable energies and the achievement of the objectives of EU-AU cooperation in the light of the COP 26 report.

SESSION 3: Energy access and socioeconomic development as primary drivers, part 2

This third session continued the theme: access to energy as the main driver of socio-economic development, and was moderated by Mrs. Rajaâ Cherkaoui El Moursli (Morocco) and Mr. Mansourou Moudachirou (Benin)

The first presentation was given by Mr. Bart Biebuyck (Belgium) on “Exploring the first large-scale hydrogen, ammonia and fuel cell related activities and projects underway in Africa. ". His presentation shows an example of a public-private partnership which aims to accelerate access to the energy system market for energy produced by new technologies. He also showed that hydrogen is an important component for the energy transition in Europe. By 2050, this energy could contribute 24% to total energy production and generate 5.4 million jobs. Fuel cell and hydrogen technology has come a long way in Europe. The collaboration between researchers, industrialists and political decision-makers has made it possible to get noticeable results and has boosted the energy transition.

Mr. Prem Jain (Zambia) from the University of Zambia and holder of the UNESCO Chair in Renewable Energy and Environment, gave the second presentation of the session on the "Growth of solar energy industry and opportunities". His presentation presents a summary of the major transformations in the field of renewable energy as a rapid replacement of fossil fuels. Major work is underway at the University of Zambia on the use of solar energy as an alternative solution.

The third presentation was given by Mr. Arnaud Zannou (Benin) on “Les enjeux de la transition vers un mix énergétique responsable au Bénin”. In his presentation, he reports the low level of development of renewable energies in Benin (9.8% in electricity supply). The government, through the Government Action Program (PAG), intends to achieve a transition towards an energy mix compatible with the needs of the country. Actions and investments are already underway to achieve this goal by 2030.

After the three presentations, the participants asked questions to the speakers. The discussions revolved around the following points: the strategy of flexibilization (turning on, off) the “on demand” systems, the source of hydrogen in Mali, the availability of training grants on renewable energies, the disadvantages of solar energy, the situation of marine energies in Benin, actions for the promotion of efficient use of energy in Benin, the stimulation of demand at the level of mini-grids, energy autonomy in the face of the import of HFO (Heavy Fuel Oil) to supply the generators of the Maria-Gleta power station in Benin and the current situation of the Adjarala hydroelectric power station between Benin and Togo.

In the frame of this session, the importance of energy efficiency was highlighted. The problem of energy efficiency has been raised in Morocco since 2009 and has been the subject of a major television campaign. Following this, the communities change the lamps to reduce energy consumption. Populations are led to return to old practices of cooling buildings which already contributed to energy efficiency.

In Benin, in 2019 the government adopted a decree which sets the standards for imported equipment to reduce energy consumption. The control of the equipment will occur at the factory before importation into Benin. Article 14 of the finance law in Benin exempted all solar equipment from customs tax to promote the use of solar equipment.

SESSION 4: Energy access and socioeconomic development as primary drivers, part 3

This last session of the first day, moderated by Mr. Norbert Hounkonnou (Benin) and Mr. Philippe De Maeyer (Belgium) continued the theme of the two previous ones.

Three communications were presented respectively by Mr. Michel Boko (Benin), Mr. Christian Rakos (Austria) and Mrs. Claude Fischer-Herzog (France).

In his presentation, *"Energy and Sustainable Development: how to change the paradigm?"*, Mr. Michel Boko recalled that life on earth and all production activities are dependent on energy. "The culture of the carbon footprint" is a new philosophy that aims to globalize the effects that development can induce at various levels. Achieving the Sustainable Development Goals (SDGs) necessarily involves the production of goods and services with the use of raw materials and energy resources. According to the communicator, this generates environmental nuisances either in the form of greenhouse gases or in the form of waste.

From the presentation by Mr. Christian Rakos, "Pelletized agricultural residues as alternative cooking fuel for Africa", we can conclude that the use, in suitable domestic homes, of locally available residues, such as rice bran, transformed into pellets, allows to eliminate air pollution caused by the use of charcoal in the kitchen. In addition, this use of pellets from waste avoids wasting wood to produce heat with very poor efficiency (less than 15%).

The third communication was by of Mrs. Claude Fisher-Herzog "Vers un pacte de solidarité énergétique en Afrique de l'Ouest pour l'industrialisation de la sous-région. Quelles coopérations avec l'Europe ?", which highlighted all the energy potential available to Africa (gas, oil, hydroelectricity, coal, uranium, sun and sea). For this, it will be necessary to strengthen public/private partnerships. The questions that arise are: how to mobilize international funds? What can Africa learn from EU energy models? How can we better use development aid and turn it into investment aid? How to organize positive mobility for technology transfer and skills training?

Mrs. Claude Fischer-Herzog's presentation also showed that nuclear energy has the lowest carbon footprint. From the point of view of climate protection, it is better suited than fossil fuels. But waste management is a problem. The solution currently used in France is to bury them 500 meters underground (in steel containers under solid concrete). What must be avoided is nuclear weapons. Africa needs civilian nuclear energy.

2nd day of the international conference SE4A (09 NOVEMBER 2021)

SESSION 5: Appropriation of renewable energy technologies, dispatchable (hydroelectric, biomass) as well as non-dispatchable (sun, wind) energies

The first session of the second day focused on the appropriation of renewable energy technologies, both available at all times (hydroelectric, biomass) and available only at certain times (sun, wind)

It was moderated by Messrs. Bernard Mairy (Belgium) and Hippolyte Agboton (Benin).

Speakers were: Mr Joris Proost (Belgium) *"Hydrogen: a Sustainable Facilitator for Decentralized Electricity Production (and Consumption)"*, Mr Jean Bosco Niyonzima (Burundi) *"Flow measurements conducted on the Mwogere River in Burundi with an hydrometric current meter using the reduced points-method in order to use a small Banki-Michell hydraulic turbine"*, Mr. Patrick Hendrick (Belgium) *"Mini hydro as an off-grid electricity solution for communities in villages in Africa, South America and Asia"*, and Laurent Albert (France) and Francisco Francisco (Mozambique) *"General opportunities & advantages of wave power for Africa, including the advantage of wave power's ability to mitigate intermittency (Ghana project)"*

The presentations focused respectively on hydrogen for decentralized electricity, hydropower for stand-alone rural electrification, and finally, wave energy, an innovative way to exploit wind energy, demonstrated by a concrete realization.

The session ended with questions and answers relating in particular to the recoverable powers on the coast of West Africa, addressed to Mr. Laurent Albert and Mr. Francisco Francisco who replied that the conversion of wave energy in electricity had an efficiency of 40%, which is a good rate compared to solar and wind energy. In response to other questions, it was specified that the lifespan of a generator (placed under water) of electricity from wave energy was estimated at around twenty years. It was also precised that, to produce 2 Megawatts, you need 20 of these generators. For these reasons, the costs of producing electricity from waves are lower than from photovoltaic panels or wind turbines.

In the field of hydrogen, it was reported that a memorandum of understanding (MoU) had been signed in the framework of COP26 between Belgium and Namibia for cooperation between the two countries in the field of production of green hydrogen, which will then be imported into Belgium.

Due to lack of time, two questions remained unanswered: is it possible to couple mini-hydroelectric power plants in an electricity network capable of supplying a city (stability of frequency and voltage, etc?) and what type university research (collaborative) is still needed to improve mini-hydropower plants?

SESSION 6: Energy systems that are secure, competitive and compatible with a sustainable and inclusive development of the continent (part 1)

The theme of this session is "Energy systems that are secure, competitive and compatible with a sustainable and inclusive development of the continent".

It was moderated by Mr. Marc Lobelle and Mr. Bernard Mairy (Belgium).

Speakers were Mr. Wisdom Ahiataku-Togobo (Ghana) "Energy systems that are secured, competitive and affordable, and compatible with a sustainable and inclusive development of the continent", Mr. Youssouf Ali Mbodou (Chad) " Système de paiement échelonné «Pay As You Go» : rendre l'énergie solaire accessible pour les ménages et les petites entreprises" and Mr. Luc Van Den Durpel (Belgium) "Nuclear Energy Tomorrow as Critical Enabler towards a Sustainable Future", all three speaking by videoconference.

After drawing attention to the abundance of resources available to Africa, Mr. Wisdom Ahiataku-Togobo presented in a very well-documented way the evolution of the production and use of electrical energy in a few significant countries in the world and then in representative sub-Saharan African countries. He finds significant differences in the energy mixes that are typically linked to the energies available in each country. Diversification is low everywhere; the main renewable energy is hydroelectricity but production depends on rain which varies greatly from one year to another. In Africa, the gas has been used for about ten years to compensate to a certain extent for these irregularities and it is produced on site. On the other hand, oil and uranium are mainly exported raw and bought - too expensive - refined, like coffee and cocoa. He concludes with the need for African countries to unite to exploit and process locally the available resources to have enough energy at an affordable price.

Mr. Youssouf Ali Mbodou, a young Tchadian industrialist, presented the “Pay As You Go” payment system of small photovoltaic infrastructures that is proposed by his company to make solar energy accessible to households and small businesses.

Mr. Luc Van Den Durpel explained that renewable and nuclear energies are complementary in reducing CO2 emissions. Nuclear energy stands out for its excellent EROEI (Energy Return On Energy investment), which is higher than that of renewable energies. The fuels of the nuclear power plants of tomorrow will be the waste of the current power plants. They will therefore also play an important role in reducing the volume of this waste.

The session ended with questions and answers on the presentations.

Mr. Youssouf Ali Mbodou clarified what happens when a customer can no longer pay his monthly payment. Although being a social enterprise, a contract is signed with the customers. After two months without payment (200 CFA francs per day), the kit can be recovered. It is then resold cheaper to another user, its lifespan being 5 years. The introduction of solar energy is not without difficulty and there are dropouts, even in programs such as "pay as you go".

Mr. Wisdom Ahiataku-Togobo explained that the concept of clean coal relates to technologies to remove carbon from the gases resulting from the combustion of coal, in order not to release carbon into the atmosphere. If we are to continue to use coal, we will have to follow environmentally friendly procedures. We must also encourage reforestation and the preservation of our ecosystem.

He also pointed out that Africa exports coffee and cocoa at low prices because, due to the lack of access to cheaper energy, it is not possible to transform these seeds, nor the crude oil into products with high added value at a competitive cost. If Africa controlled its access to electricity, it would be possible to have strong industries and thereby become more competitive in the sector.

Mr. Luc Van Den Durpel specified that Ghana has been committed to a nuclear agenda since 2010. The country is working to become a nuclear country. In 2020, a nuclear plant was decided in partnership with the IAEA nuclear agency in order to reach full operation in 2030. He agrees that it would be better for nuclear energy to be developed at the level of ECOWAS. The 13 countries of ECOWAS and even all of Africa should unite and work in synergy to develop nuclear power as has been the case on other continents.

SESSION 7: the session covered two themes.

It was moderated by Mr. Michel Boko (Benin) and Mr. Jean Snoeck (Belgium)

Theme 3: Energy systems that are secure, competitive and compatible with a sustainable and inclusive development of the continent (part 2)

The first communication of session 7 entitled *"Calcul de l'écoulement de puissance dans les réseaux de transport électrique par la méthode de Newton-Raphson : application au réseau de transport électrique de la Communauté Électrique du Bénin"* was presented online by Mr. Mawuena Medewou from Benin. He explained the results of the study carried out on load flow on the CEB's existing transmission network. Then, solutions were proposed, in particular for compliance with the requirements relating to the level of voltage required on the interconnection lines or at the connection points with neighbouring operators. Thus, after the inventory of the CEB's transport and production infrastructures, a single-line diagram of the network was proposed.

Theme 4. Management of energy-based services in an inclusive and sustainable way (in rural and urban regions) (part 1)

The second paper of session 7 is entitled *"Renewable energy and productive water for irrigation purposes in the provinces of Monica and Zambezia, Mozambique"* and presented online by Mr. Mark Tjebbe Hoekstra (Netherlands). It can be noted that the use of renewable energies for irrigation purposes integrates synergies between energy production and the use of dam water for agricultural production while respecting ecosystems that are particularly vulnerable to climate change. This is essential for sustainable human development. These ENABEL interventions in Mozambique were carried out between 2010 and 2016.

The third communication was outside the scope of the conference, unrelated to the abstract accepted by the program committee and, therefore, aborted by the organizers.

After these communications and to close the session, a few questions were put to Mawuéna Medewou. When asked whether there is a CEB plan to free Benin from the need to import electricity from two neighboring countries, it is answered that, on the contrary, it is a question of making bi-directional this interconnection; this is the aim of the WAPP. This way, Benin could be an exporter as well as an importer of electricity. This is all the more important with renewable energies as they may be unavailable in one place, while available somewhere else. Other questions, related to stabilizing the frequency of the network and applying the results of the study remained unanswered because they were outside the scope of the study.

SESSION 8: the session covered two themes.

This session was moderated by Mrs. Rajaâ Cherkaoui El Moursli (Morocco) and Mr. Brice Sinsin (Benin)

Thème 4 : Management of energy-based services in an inclusive and sustainable way (in rural and urban regions) (part 2)

This session was moderated by Mrs. Rajaâ Cherkaoui El Moursli (Morocco) and Mr. Brice Sinsin (Benin).

The first communication, presented online by Mr. Shaukat Abdulrazak, is entitled "IAEA's contribution to capacity building in Africa for sustainable nuclear energy solutions". It can be noticed that the IAEA helps its Member States to apply nuclear technology safely and sustainably in various fields, including for the analysis, planning and supply of energy systems. The Technical Cooperation Program of IAEA is the main delivery mechanism for this support.

The second presentation, pre-recorded by Mr. Christopher Kost (USA), is entitled "Sustainable and Equitable Mobility for African Cities". Mr. Kost spoke about building cities with high quality pedestrian and cycling facilities, efficient public transport and better use of land-transport, illustrating his talk with case studies such as the Kisumu Triangle project and the Dar es Salaam City Rapid Bus.

Theme 6: Energy supply chain for all types of consumers

The third communication of this session is a pre-recording by Mr. Yannick Useni-Sikuzani entitled: "Le Projet CHARLU, vers une gestion durable de la ressource bois-énergie pour une offre sécurisée en charbon de bois et une réduction de la déforestation du Miombo ". This is a project that aims to improve the practices of different actors vis-à-vis forest resources by (i) improving the governance of forest resources, (ii) assessing the spatial footprint of deforestation when considering forest plantations for energy purposes, (iii) quantifying the stocks of nutrients in deforested areas, (iv) optimizing the carbonization yield.

POSTER SESSION

This session, which closed the second day, was intended to allow the authors of the posters to briefly present (in 3 minutes) their results in plenary session.

It was moderated by Mr. Antoine Vianou (Benin) and Mr. Philippe Goyens (Belgium).

The posters that were presented are as follows:

Wirnkar Nsanyuy (Cameroon) – *“Fault identification in Distribution transformers: Case of Fako Division, Cameroon”*

Pierre Kpantingnangan (Benin) – « *Transformation des résidus agricoles, forestiers et déchets biodégradables en ‘charbon vert »*

Pierre Kpantingnangan « *Transformation des résidus agricoles et déchets biodégradables en ‘biogaz’ »*

Talata Soulemane Modibo Karim (Benin) « I*nnovations énergétiques, activités génératrices de revenus des femmes et développement inclusif durable au Bénin »*

Coffi Adihou (Benin) « *Étude de la performance d'un chauffe-eau solaire compact à absorbeur muni d’ailettes par le critère d'Entransy détruit »*

Victor Zogbochi (Benin) « *Production d’énergie électrique en milieu africain : exemple du moteur Stirling »*

Rock Dake (Bénin) « Use *of sorption materials in solar dryers for sustainable production »*

3rd day of the international conference SE4A (10 NOVEMBER 2021)

SESSION 9: Optimisation of energy based services for big consumers

This session was moderated by Mr. Marc Lobelle (Belgium) and Mr. Jean Snoeck (Belgium)

The first communication, presented remotely by Mr. Emmanuel Ackom (Ghana) *“Close-by yet inaccessible: Urban poor communities and modern energy conundrum in Africa”* concerned access to electrical energy in poor urban and peri-urban areas. After showing the obvious correlation between prosperity and access to energy, Mr. Ackom presented the results of a United Nations UPEA (Urban & Peri-urban Energy Access) study of informal poor neighbourhoods in Dakar, Nairobi and Cape-Town. Obstacles to the electrification of these areas exist both on the side of the electricity distributors (no property deeds, no addresses, no planning relating to these areas, no personnel security in these areas) and potential consumers (too poor to pay, unaware of the risks and efficiency of connections, lack of trust in authorities). Also many “informal” connections to the network cause problems. Roads for improvement would be the allocation of temporary addresses and temporary settling locations, setting up prepaid services, informing potential users about electricity, its usefulness and good practices.

The second paper, presented on site by Mr. Joseph Essandoh-Yeddu (Ghana) *“Natural Gas Use and Perspectives: Opportunities for Intra- and Inter-African Trade”*, presented, in a very well documented way, a well-known energy source in Europe but whose use is recent in Sub-Saharan Africa: natural gas. It has several qualities that make it increasingly attractive: the cleanest fossil fuel that can be used for many applications: petrochemicals, heating, electricity and hydrogen production, transport. It is the least harmful fossil fuel to support the transition to renewables, of which it can compensate for the intermittent nature. Africa has 7% of the world's known resources and production. Pipelines, some operational, others planned, make it and will make it even more accessible to African users Typically, the WAGP, built in 2005-2008 and operational since 2009-2010, allows Benin, Togo and Ghana to use Nigerian natural gas. The pipeline is currently only used at 30% and is already helping to stabilize electricity production in these countries.

The discussion focused on the second presentation, in particular on the lack of a real policy of pooling efforts and resources at the level of African countries. Ghana is clearly ahead of its neighbours in terms of energy for a long time thanks to the dam on the Volta, since 1965, which not only was a significant source of energy for the country but also allowed it to supply neighbouring countries. The droughts, which reduced the flow of this dam, and the increases in consumption forced Ghana to find complementary sources of energy, especially gas and nuclear for which they created the necessary administrations to ensure this development. The chaotic political evolution of the DRC for decades has not allowed it to create such structures to develop their potential (Inga dams) as effectively as Ghana.

The WAGP (West African Gas Pipeline) is still operating at only 30% of its nominal capacity. Is it a technical problem (lack of compressor), a lack of consumers, a lack of supply?

SESSION 10 : Materials and sustainable development

Session 10 focused on Theme 7 “Materials and Sustainable Development”.

It was moderated by Mr. Marcellin Amoussou-Guénou (Benin) and Mr. Bernard Mairy (Belgium).

Three papers were presented by Mr. Hervé Jeanmart (Belgium); Mr. Thierry Duvaut (France) and Mr. Thierry d'Almeida (Benin)

Mr. Hervé Jeanmart (Belgium) *"The Energy Return on Investment (EROI) and the accessibility of renewable energy"*. insisted, by videoconference, on the need to use the concept of EROI, defined as the ratio between the energy produced during the lifetime of an installation and all the energy required to build, operate, maintain and dismantle it.

Mr. Thierry Duvaut (France) *"Quels peuvent être les impacts d’une recherche et d’un enseignement scientifiques pluridisciplinaires sur la problématique générale liée à un système urbain durable (cas d’un campus universitaire par exemple), et sur le quotidien des citoyens ??"* presented, also by videoconference, the example of the Eco-campus of the University of Reims. This is an area of intense university life within the city. It was designed as a model of a productive, compact, 0 waste (waste recycling), nature friendly, encouraging sustainable mobility (soft mobility), flexible, energy demonstrator, scalable campus with islands of buildings and operating in a circular economy. He insisted on the promotion of local materials, taking the example of construction experiments that consume little energy, such as that of the energy laboratory of the EPAC (University of Abomey-Calavi, Benin) and the bricks made from typha produced in Senegal.

Mr. Thierry d'Almeida (Benin) "The X-TechLab initiative in Benin: a regional platform dedicated to capacity building in science education". explained, in person, that X-TechLab is a platform dedicated to the use of X-Ray techniques in the service of scientific and technological research around development issues specific to the African continent. It is supported by the Sèmé City Development Agency (ADSC), a government agency responsible for implementing one of the flagship projects of the Government's Action Program, the International City of Innovation and Knowledge. The platform has set itself two main objectives: (i) to train the scientific community of Benin and the sub-region to integrate X-ray techniques into their research work, (ii) to contribute to the emergence at the continental level of a community of experts in X-ray techniques who will be able to animate the future pan-African synchrotron and define its priorities.

The discussions mainly focused on the X-TechLab project and concerned the financing aspects of the program, collaborations with other African countries; the inclusion of nanotechnologies in the program, the mechanisms for granting training grants.

In response, Mr. Thierry d'Almeida clarified that Seme City is not yet working on nanomaterials, but this is in perspective. There are collaborations with several universities including the University of Cape Town and others in Nigeria. More than 80% of the programs are financed by Benin. But there is also EU funding in the form of training grants for nationals of other African countries.

SESSION 11: Reinforcement of education and research capacities and valuation of scientific expertise in Africa

The session, moderated by Mrs. Rajaâ Cherkaoui El Moursli (Morocco) and Mr. Antoine Vianou (Benin), focused on strengthening teaching and research capacities and promoting scientific expertise in Africa. All presentations were by videoconference.

It took into account 5 communications led by Mr. Léonard Lévêque (France); Mr. Hamid Aït Abderrahim (Algeria/Belgium); Ms. Sandra Soares-Frazao (Belgium); Mrs. Alina Iatan (Romania) and Mrs. Glory Oguegbu (Nigeria).

Mr. Léonard Lévêque (France) *"Long-Term Joint European Union - African Union Research and Innovation Partnership on Renewable Energy"* presented a program, abbreviated LEAP-RE, which aims to put in place the foundations of a solid partnership between EU and Africa.

It is noted that several public and private organizations, academies and research laboratories are involved in the project. It involves specialists working on the renewable energy program in both continents.

In his presentation, Mr. Hamid Aït Abderrahim (Algeria/Belgium) “*Nuclear energy for Africa and by Africa: dream or reality - The development of Small Modular Reactor (SMRs) for emerging nuclear countries in Africa”* showed that small nuclear reactors may be a good option for Africa. This is possible with a good dynamic of collaboration. He also raised issues that need to be considered when choosing reactors. He presented nuclear technology experiments currently under development. This is the example of the ongoing Myrrha project in Belgium.

Ms. Sandra Soares-Frazao (Belgium) *"Distance learning in hydraulics: MOOCs and beyond"* presented the experience of converting one of her courses into a MOOC (Massive On-line Open Course) which covers, after an introduction to hydrology, the theory of surface flows, the calculation of water profiles and applications to certain specific situations such as channels with changes in bed slopes, changes in channel width, Venturi channels, flows between piles of bridges. It is noted that several African countries have followed the videos. It is therefore an opportunity for new teaching formats. The resources can also be used by other teachers to reinforce their training.

Mrs. Alina Iatan (Romania) *"EU CBRN Center of Excellence Strengthening preparedness on CBRN incidents in Africa. "* presented a project with 62 partner countries including some from Africa. Among other things, the center is involved in: strengthening health laboratories to minimize potential biological risks, and health security in ports, airports and border crossings.

Mrs. Glory Oguegbu (Nigeria) showed how innovation and capacity building will disrupt the sustainable energy space and contribute to climate action

Mr. Philippe Schild (France) *"EU-Africa Science, Technology and Innovation Cooperation: Perspective"* presented the European policy for the intensification of cooperation between the European Union and the African Union in the fields of research and innovation. This policy is part of the Horizon Europe 2021-2027 program and is already bearing its first fruits in the EFFECT (European Forum for Enhanced Collaboration in Teaching), SOPHIA (Human-robot interactions) and especially SESA (Smart Energy Solutions for Africa) projects.

SESSION 12: Multidisciplinary approach for a sustainable access to energy.

This session was moderated by Mr. Phillipe De Maeyer (Belgium) and Mr. Brice Sinsin (Benin) and concerns the multidisciplinary approach to sustainable access to energy.

The first communication, pre-recorded, was presented by Mr. Bob van der Zwaan (Netherlands) "*An Integrated Assessment of Pathways for Low-Carbon Development in Africa"*. It is a forecast analysis of what Africa's energy demand could be until 2050, and examines scenarios for the concomitant levels of greenhouse gas emissions and emission intensities.

The second presentation, also pre-recorded, by Mr. Dimitrios Mentis (USA) is entitled *"Energy Access Explorer, a dynamic geospatial information system to connect SDG 7 and sustainable development outcomes".* This communication presented a dynamic geospatial information system (Energy Access Explorer) to connect SDG7 and sustainable development outcomes.

The third presentation, also pre-recorded, made by Mrs. Monica Gullberg (Sweden) is entitled *"African energy demand – the key to innovation"*. The observation is that today, approximately 840 million people do not have access to electricity. Rectifying this situation requires effectively expanding access to energy. Government planners must understand and have access to data and analytical tools that capture the key attributes of the unserved and poorly served people they are trying to reach.

The fourth presentation, made in person by Mr. Satyanarayana Narra (Germany), is entitled *"Flexibilization of the sustainable energy supply in Ghana: a contribution by waste to electricity conversion".* This communication presented studying and demonstrating the possibilities of hybrid systems associating photovoltaic and bio-gas produced from waste in order to be able to meet electricity needs in a flexible way, compensating with bio-gas the intermittent nature of solar energy. This system also makes it possible to recycle waste rather than dumping it in landfill. A demonstration pilot plant is currently being built in Ghana.

To close this session, we had a fifth presentation made in person by Monique Ouassa-Kouaro (Benin) on "Access to electrical energy and improvement of household living conditions: major issue and challenge for sustainable development in Benin". In her presentation, the authors demonstrated that the current system of production and distribution of electrical energy in Benin does not guarantee quality energy services in sufficient quantity. Thus, the energy dependence combined with the non-existence of an appropriate electricity network infrastructure and the failure to exploit the sustainable energy potential limit the access of populations, particularly those in rural areas, to a reliable and quality energy system capable of boosting the creation of wealth. This energy dependence does not allow the achievement of the objectives of sustainable development in Benin.

The question & answer session of this session revolved around the presentation of Mr. Satyanarayana Narra. The main concern was the type of software to use to optimize the operation of the hybrid system presented.

4th day of the international conference SE4A (11 NOVEMBER 2021)

The day was devoted to two series of seminars organized in parallel, respectively in the large blue room for plenary presentations and in one of the rooms upstairs.

Blue Room

Nuclear Seminar

This seminar was organized by Mrs. Rajaâ Cherkaoui El Moursli (Morocco) and Mr. Bernard Mairy (Belgium) and led by Mr. Hamid Aït Abdelrrahim (Algeria and Belgium)

Each panelist gave a ten-minute presentation. These presentations by videoconference were followed by a joint discussion.

The first scheduled panelist was Mr. Shaukat Abdulrazak, Director of the Technical Cooperation Division for Africa of the IAEA. He was represented by Mr. Neil Jarvis, section chief of the same division. The theme of the presentation was *"IAEA's contribution to capacity building in Africa for sustainable nuclear energy solutions".* Mr. Neil Jarvis presented how the IAEA can help member countries build their capacity to develop robust energy strategies, plans and programs and improve their understanding of the possible contributions of nuclear energy to achieving the sustainable development goals.

The second scheduled panelist was Mr. Marcellin Amoussou (Benin), Permanent Secretary of the National Authority for Radiological Safety and Radiation Protection (ANSRR). He was, represented by Mr. Mahougnon Boniface Zinsou (Benin), Head of the Nuclear Security Service of the ANSR. The theme of the presentation was “Etat des lieux de la réglementation de l'utilisation des rayonnements ionisants au Bénin en 2021”.

The third panelist was Mr. Vincent Lukanda Mwamba (DRC), Director of the General Commission for Atomic Energy / and the Regional Center for Nuclear Studies in Kinshasa In his presentation entitled “A propos de l’Electronucléaire en Afrique”, he explained that nuclear energy should be part of the energy mix in Africa, in particular small modular reactors (SMRs) which can provide a source of electricity to deploy the electricity grid in isolated regions and thus settle populations and reduce rural exodus to mega-cities.

The fourth panelist, Mr. Jan Bartak (France), Partner at NucAdvisor, presented “Small Modular Reactors: Economics, Safety, Advantages and Challenges”. He explained that there are already more than 50 SMR projects underway around the world and that these respond favorably to questions of security, non-proliferation, investment costs, implementation time, standardization (they will be prefabricated in the factory in series) and acceptability by the public. The American Nuscale project, based on proven technologies, is the most advanced.

The fifth panelist was Mr. Anicet Touré (Mali), Product Director for SMRs at Tractebel ENGIE. In his presentation,“Small Modular Reactors: a tool to re-shape African energy ecosystems of tomorrow?”, he explained that there are over 70 different SMR concepts in the works or in development. The investment cost of such a 100 MW reactor would be in the order of one billion dollars. Potential applications, other than electricity production, also include heat production (urban heating and industrial use), seawater desalination, hydrogen production, etc.

The sixth panelist was Mr. Henri Zaccai (Belgium) Consultant (HZC International). In “Your road to nuclear: how to deploy your nuclear energy options?”, he insisted on the fact that it is necessary to plan over 10 years the implementation of a major electro-nuclear program.

The seventh panelist Mr. Pierre Kockerols (Belgium), Senior Expert for the European Commission. In “Que faire des déchets du nucléaire. L’expérience et le savoir-faire européens en la matière”, he presented the state of the art of the management, treatment and possibilities of recovery of nuclear waste and the practices adopted by European countries.

The eighth and last panelist of the nuclear seminar was Mr. Marc Deffrennes (Belgium), nuclear analyst. In “Africatom ? Lessons learned from Euratom to foster a successful African nuclear collaboration…”, he highlighted the benefits of tackling and resolving nuclear issues together at the continental level.

The discussion focused on the future of nuclear energy in Africa. The crucial need to satisfy certain prerequisites such as the existence of a legislative framework and specialized training has been demonstrated.

The implementation of these prerequisites can benefit from the guidance of the IAEA and the support of AFCONE (AFrican Commission on Nuclear Energy). This approach has already been followed by African countries that have already opted for nuclear energy or for nuclear applications in medicine or in industrial processes such as agro-industry or for research in the nuclear field.

SMRs (Small Modular Reactor) can be combined with renewable energy sources to form a hybrid supply where nuclear compensates for the often-intermittent nature of renewables. SMRs could thus play a crucial role in the transition to clean energies.

Financial Seminar

This seminar was organized by Mr Bernard Mairy (Belgium) and led by Mrs Mireille Janssens (Belgium).

Each panelist gave a ten-minute presentation. These presentations by videoconference were followed by a joint discussion.

The first panelist was Mrs Axelle Bourreau (GD Luxembourg). In *“EIB investing in Western & Central Africa for renewable energy”, s*he explained that the EIB institution - whose 2020 budget amounted to 66 Billion Euros - intervened in 2020 for 2.7 Billion Euros in financing projects in North Africa. The EIB representative also illustrated two case-studies, respectively a EUR 1.2 Billion hydroelectric project in Nachtigal (Cameroon) and a EUR 610 Million solar farm project in Lake Turkana (Kenya).

The second panelist was Madame Natalia Svarinska (Belgium). This ElectriFI representative illustrated in *“Addressing the financing gap in access to renewable energy markets in South-Saharan Africa”*, a case-study in the PV sector in Benin (My Joule Box: EUR 1.5 Million). The “ticket size” is typically between EUR 0.5 and 1.0 Million.

The third panelist was Mrs. Medjo Wafo (Côte d'Ivoire). Her speech, *"PROPARCO: presentation and activities in the field of energy in West Africa"*, presented two case studies, respectively at Kahone & Koal (Senegal) in the PV sector (45 and 35 MWp respectively) and the BIOVEA project (biomass (46 MW) in Cameroon. The “ticket size” is typically between USD 0.5 and 200 million. PROPARCO's commitment to Africa in 2020 was EUR 290 Million (mainly in the form of loans).

The fourth scheduled panelist was Mrs Camille Fronville (Belgium). She was replaced by Mrs. Carole Maman to present *"BIO Invest facts & figures"* that illustrated two case-studies, respectively a hydroelectric project in Uganda (5.6 MW) and a 20 MWp Senergy-2 solar project in Senegal (with a 20 year Power Payment Agreement). The “ticket size” is typically between EUR 5 and 20 Million per project.

The fifth panelist was Madame Mireille Janssens (Belgium), presenting *“How can an Export Credit Agency provide financing for energy projects in Africa. The case of Credendo in Belgium "* This representative of credit insurance CREDENDO illustrated the case-study of a hydroelectric project in Kenya.

The sixth scheduled panelist was Mrs. Alzouma Nouhou (Nigeria) , but she was prevented from attending to present *“Africa Renewable Energy Initiative (AREI)”*.

The seventh panelist was Glory Oguegbu (Nigeria), RETTI representative. She reviewed in *“Investment that Works; A look at investing in the African Renewable Energy Industry; instruments and things to keep in Mind ”* a number of financial instruments suitable for the renewable energy sector.

The seminar covered several case-studies of investment in energy projects of different types (hydroelectric, solar, biomass), of different budget sizes and carried out thanks to different and innovative financial instruments.

Seminar room upstairs

Solar Seminar

This seminar was organized by Mr. Léonide Sinsin (Benin) and Mr. Bernard Mairy (Belgium) and moderated by Mr. Léonide Sinsin.

Unlike the two previous seminars which were mainly aimed at decision makers from all over Africa, this seminar was specifically aimed at an audience of practitioners and candidate practitioners and concerned the profession of installer of solar energy production infrastructures. The panelists were, for the most part, Beninese professionals in the field and all present on site. Most of the other participants in the seminar were teachers and students of solar energy.

Each panelist presented two interventions of 8 minutes each. Each series of interventions was followed by a question-and-answer period. The panelists were:

Mr. Badr IKKEN (Morocco) from IRESEN. He presented the energy sector in Morocco, and the place occupied by research, applied research and innovation for the expansion of the sector. The focus was on IRESEN, Institute for Research in Solar Energy and New Energies, whose activities cover training with a business and scientific approach, and innovation. Its objective is that Morocco and the continent becomes not only a consumer of finished products, but a melting pot of production of exportable knowledge.

Mr. Erik HOUGNINOU (Benin), technical expert of the Regulatory Authority (ARE) presented his institution which monitors compliance with the legislative and regulatory texts governing the sector and the promotion of it through the opinions it issues on all investment projects (thermal, renewable, hydro), the revision of electricity tariffs or even public consultations.

The presentation of the regulation allowed to make a macro analysis on the state of the sector which was reframed on the role nowadays of a company dedicated to the production.

Mr. Vivien AGABKOU (Benin) of the Beninese Electricity Production Company (SBPE) recalled the daily challenges it faces, with already tangible results (strong reduction in load shedding, control of production costs thanks to the optimization of production sources, renegotiation of framework contracts that governed sub-regional imports).

Mr. Zacharie PAPANAM (Benin) from the German Cooperation (GIZ), donor and technical and financial partner, spoke about his role alongside the most vulnerable populations. For several years, GIZ has been working, following a results-based financing (RBF) approach, to co-finance the cost of access to certified solar systems in order to reduce the final price for the household. The principle of the RBF consists in launching at the beginning of the year a call for projects to which companies apply. Following a rigorous process, the subsidy can be up to 37% of the selling price of the product.

Mr. Josaphat TONOUDJI (Benin) from ARESS, one of the companies that has benefited the most from this support, then presents this pan-African group, currently established in 4 West African countries (Benin, Togo, Burkina Faso, Senegal). ARESS aims to become an energy operator. It already impacts the lives of more than 50,000 direct beneficiaries, and more than 2 MWp deployed in the countries of action. The acceleration of its services has above all been possible thanks to the integration of Pay As You Go (PayGo), which is an innovative financing mechanism allowing tracking and payment technology to be embedded in a solar product, and to be offered as a package to the end consumer, at a lower price than conventional microfinance.

Mr. Alain TOSSA (Benin), professor at EPAC-Abomey-Calavi and 2iE-Ouagadougou presented the state of the art of training in engineering professions which are no longer in line with market needs. It therefore seems important to review the curricula, with the involvement of companies, but above all, to better train trainers to be avant-garde in technological and strategic choices for future generations.

Mr. Joel AKOWANOU (Benin) of MCA Benin II, recalled the importance of coordinated actions for an investment to be both impactful and sustainable, as evidenced by the different areas in which MCA Benin II has been involved since 2016.

By way of opening the second part of the exchanges Mr. Badr IKKEN insisted on the importance of training highly qualified personnel, with logistical and financial means to ensure influence, especially in times of strong international cooperation. The same is true for most stakeholders, who recall the importance of having qualified personnel, but above all training, the objectives of which must be geared towards employability and sector monitoring.

The questions from the public mainly revolved around the new technologies in force in the field of solar PV, internship opportunities, national and international, and the maturity of international projects to be relayed by governments and national institutions. The seminar ended with a general satisfaction of the participants and the panelists, but especially the warm congratulations to the Benino-Belgian organizing committee.

Seminar on the training of experts for Africa

This seminar was organized by Mr. Norbert Hounkonnou (Benin) and Mr. Marc Lobelle (Belgium).

This seminar made it possible to get an idea of the content of the training courses in progress in Benin and Morocco in the field of energy, based on the presentations made by Mr. Basile Kounouhewa (Benin) and Mr. Badr Ikken (Morocco).

This has shown that each state was able to organize basic training as well as more advanced training in which a large number of experts is needed in each country, but that there are needs for more specific training which should be jointly organized at continental level.

The participants agreed to meet at a later date to concretely discuss the contours and content to be given to the project to train energy experts for Africa in a spirit of pooling skills at the national, regional and international level.

CONCLUSION

At the end of these four days of exchanges, the objectives of this conference have been achieved. 67 strategic, scientific, economic and technical communications were presented (37 plenary, 24 in seminars and 7 short-poster presentations). The work was organized into 11 plenary oral communication sessions, a poster session, four seminars (on nuclear, solar, financing and training of energy experts for Africa).

A number of planned presentations (23) could not take place, mainly due to professional impediments or technical failure.

Plenary presentations covered nine themes.

- Access to energy as a driver of socio-economic development.
- Appropriation of renewable energy technologies, both permanently available (hydroelectric, biomass) and part-time available (sun, wind).
- Control of energy systems that are secure, competitive and compatible with the sustainable and inclusive development of the continent.
- Management of energy services in an inclusive and sustainable manner (in rural and urban areas).
- Optimization of energy services for large consumers.
- Control of the energy supply chain for all types of consumers.
- The use of materials for sustainable development.
- Strengthening teaching and research capacities and promoting scientific expertise in Africa.
- The need for a multidisciplinary approach for sustainable access to energy.

During the sessions, the speakers presented different approaches and strategies used in the field of energies. It was essentially a state of the field in terms of energy availability, challenges and prospects for Africa.

The rich and diversified presentations took into account a panoply of energy sources (wind, solar, nuclear, hydraulic, etc.). Examples of the energy mix of certain countries were also shared. Renewable energies were presented as a potential catalyst for socio-economic development in Africa. In addition, emphasis was placed on the use of local materials in achieving energy efficiency. In addition, cooperation in research and innovation in the energy field was a central point of the discussions. Which have been nurtured to high scientific levels. Among other things, it emerges:

- the need for nuclear energy technology for Africa and in this sense small nuclear reactors may be a good option;
- the need for Africa to diversify its renewable energy sources;
- The importance of pooling energy resources.
- The need to work together to organize advanced training for experts.

Directions for reflection are open to enable Africa to make strategic choices in order to achieve a transition towards an energy mix compatible with its needs. This requires the commitment of all stakeholders and real political will.

The conference presents its gratitude to the government of Benin for agreeing to host it in Cotonou and for contributing in every way to its smooth running. It would also like to thank the Kingdom of Belgium and in particular the Royal Academy of Overseas Sciences of Belgium for having chosen Benin to hold this edition and for the facilities provided for its success.

Finally, the conference presents its sincere congratulations to all the participants, to the organizers and thanks the women and men of the press for their support.

ANNEX:

COMMUNICATIONS THAT COULD NOT BE PRESENTED

- **Energy access and socioeconomic development as primary drivers.**
  - Faustin Dahito (Bénin) « Les business models de la transition énergétique en Afrique de l'Ouest (CEDEAO) »
  - Badr Ikken (Maroc) « Three new research and innovation platforms in Morocco »
  - *Daniel Ketoto Ounda (Kenya) « Kenya's Role in Maximizing Generation Mix for Attaining Sustainable Development Goal (SDG) No. 7 »*
  - *Fabrice Lusinde (RDC) « Acteurs, enjeux et perspectives de l'industrie de l'électricité en République démocratique du Congo... En attendant Inga 3 et Grand Inga »*
  - *Atef Marzouk (Egypt) « Role of Geothermal in Renewable Energy Mix »*

- **Appropriation of renewable energy technologies, dispatchable (hydroelectric, biomass) as well as non-dispatchable (sun, wind) energies**
  - Yezouma Coulibaly (Burkina Faso) « *Renewable Energy (RE) penetration rate: Reliable energy, Energy accounting and Energy Indicators for African countries* »
- **Energy systems that are secure, competitive and compatible with a sustainable and inclusive development of the continent**
  - Edi Assoumou (Bénin) « *Challenges of long term power system transition in West Africa: the case of the Ivory Coast* »
  - Douglas Baguma (Ouganda) « *Remot, an IoT digital tool made in Africa for off-grid energy systems* »
  - Joseph Thokozani Mwale (Zambie) « *The Conundrum of Sustainability of Hydro-Electric Energy as a Renewable Energy Source under Climate Change: Implications for the Resilience of the Water-Energy-Food Nexus of Southern Africa* »
- **Management of energy-based services in an inclusive and sustainable way (in rural and urban regions)**
  - Samuel Igbatayo (Nigeria) « *Harnessing waste-to-energy value chain to achieve sustainable development goals : lessons for Sub-Saharan Africa* »
  - Susan Pendame (Malawi) « *Electricity Access and Economic Development: The Case for Productive Use of Off-Grid Renewable Energy in Rural Africa*. »
  - Sandiswa Qayi (Afrioque du Sud) « *Energy Challenge in Africa using case study of AET innovations in energy efficiency* »
- **Optimisation of energy based services for big consumers**
  - Edgar Gnansounou (Bénin) « *Sustainable Strategy for Transportation Fuels in West-Africa: A 2050 Prospective Assessment* »
- **Energy supply chain for all types of consumers**
  - Eddie Bilitu (RDC) « *Electrification des milieux ruraux par les micro-centrales hydroélectriques en RD Congo* »
  - Arthur Minsat (France) « *How sustainable energy in intermediary cities will strengthen Africa's food value chain* »
  - Bruce Sithole (Afrique du Sud) « *Extracting Maximum Value from trees* »
- **Materials and sustainable development**
  - Bothwell Batidzirai (Zimbabwe) « *Energy access in Sub-Saharan Africa: Lessons from community engagement in rural Uganda and Zambia* »
  - Fouzia Cherkaoui El Moursly (Maroc) « *Polyanions phosphate and phosphite materials for Li-Ion Batteries: Moroccan resources valorization* »
  - Kenneth Ozoemena (Afrique du Sud) « *Energy storage landscape in South Africa and the rest of Africa* »
- **Reinforcement of education and research capacities and valuation of scientific expertise in Africa**
  - Bonaventure Banza Wa Banza (RDC) « *Electrification des quartiers périphériques de Lubumbashi (RD Congo) par le biais des mini-réseaux hybrides PV-Diesel* »
  - Niclettte Bukasa Kampata (Belgique-RDC) « *Long-Term Joint European Union - African Union Research and Innovation Partnership on Renewable Energy* »
  - Tsopgni Vadel Eneckdem (Cameroon) « *Contribution of mapping to wind power, solar photovoltaic and hydroelectric energies potential assessment from the highlands of Bitchoua* (West Cameroon)
- **Multidisciplinary approach for a sustainable access to energy.**
  - Léonard Kabeya (RDC) « *Modèle simple d'accès à l'énergie verte consommable par les femmes en milieu rural face à la résilience au changement climatique en Afrique* »

Acknowledgements

The editors wish to thank, for their support of this event, the organizing academies (in alphabetical order) ANSALB (Académie Nationale des Sciences , Arts et Lettres du Bénin) and RAOS (Royal Academy of Oversea Sciences of Belgium), especially (from ANSALB), prof. Nazaire Padonou (president), prof. Hippolyte Agboton (former perpetual secretary), Mrs.Sandrine Hounsou, Mrs. Anita Fadotey, (from RAOS), prof. Philippe de Maeyer (perpetual secretary), prof. Philippe Goyens (former perpetual secretary), Dr. Ir. Georges Van Goethem, Mrs. Claudia Godinho, Mrs. Patricia Bulanza, Mr. Thomas De Wolf.

They also wish to thank for their support and active participation the Minister of Energy of Benin, Mr. Dona Jean-Claude Houssou, the Minister of Higher Education of Benin, prof. Eleonore Yayi Ladekan, the Ambassador of Benin in Belgium, SE. Zacharie Akplogan, the Ambassador of Belgium in Benin, SE. Xavier Leblanc, the ambassadors of Morocco, SE Rachid Rguibi , the ambassador of Egypt, SE Afifi Amal and prof. Fadila Boughanemi, representing the EU.

They, of course, wish to thank the other members of the scientific committee, Dr. Thierry D'ALMEIDA, Dr. Badr IKKEN, prof. Prem JAIN, Ir. Léonide Michael SINSIN, Dr. Ir. Jean SNOECK and Dr. Ir. Georges VAN GOETHEM.

They finally wish to thank the local organizer, Prof. Ezinvi Baloïtcha , and the designer of the SE4A logo, Mr. Hugues Bertiaux.

Sponsors who contributed to the travel expenses of several African participants deserve thanks for their contributions: SEII (European Society of Enginerrs and Industrialists) and IAEA (Internatinal Atomic Energy Agency).