



**Proceedings of the International Conference on
Energising the SDGs through appropriate technology and governance**

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Foreword

The Institute of Energy and Sustainable Development (IESD) in Leicester has been engaged over the past decades in promoting research on sustainable development using its systems thinking approach. The interconnectedness of global issues and the need for an integrated approach has now been adopted and mainstreamed by the United Nations' Sustainable Development Goals (SDGs). The transformational agenda of the SDGs has received global attention and De Montfort University of Leicester has committed itself to supporting the SDGs in every aspects of university life, including teaching, research and student support. The decision to organise a conference to showcase research activities supporting the implementation of the SDGs follows from the above context.

The vision of the Sustainable Development Goals (SDGs) is to transform living conditions of all people on the Earth so that we can live within the 'planetary boundaries' while enjoying economic prosperity and social wellbeing. The transformative change aimed through the SDGs requires a paradigm shift in thinking to break away from the current development trajectories that are resource intensive, inefficient (hence wasteful), environmentally damaging, growth-driven, and socially inequitable and unjust. The Sustainable Development Goals (SDGs) offer the opportunity to approach sustainable development in an integrated, interconnected way.

However, building 'the world we want' and reaching the SDGs by 2030 faces a number of major challenges which require innovation, including:

Demanding timelines. To reach the SDGs by 2030 would require a Marshall-like plan that has to be implemented meticulously. In many areas, implementation needs to shift from evolutionary to revolutionary timelines. Our understanding of the issues, evidence to support the decision-making process and our ability to analyse the issues effectively and manage progress in a timely manner will hinder progress.

Weak governance. Countries facing the greatest challenges are mostly low-income countries, with weak governance arrangements. Can top-down management approaches by governments be strengthened so that a Marshall-like Plan can be effectively implemented? Designing a modern governance arrangement that can work in these countries remains a challenge. On the other hand, the co-creation of sustainable bottom-up solutions at a decentralised level needs to be supported through innovative thinking, open knowledge sharing, business ideas, and empowering local communities and actors.

Complexity. As SDGs are an interconnected and integrated set of targets, better understanding of their inter-relationships, synergies and conflicts is required. The human-nature interactions in the primary, secondary and tertiary sectors affect the natural capital, ecosystem services, human capital development, natural environment, the climate and the communities. Our understanding of these interactions is still incomplete and scientific research can surely improve our knowledge. Lack of innovation **ecosystems** in many developing countries. The relationships between institutions, policymakers, researchers, change agents on the ground and communities, with open access to developmental resources, all need to be enhanced.

In this context, the conference considered how appropriate technologies and governance arrangements can support the achievement of the SDGs by 2030. While technology has shaped

the past development, it has also contributed to environmental damages, inequality, social and ethical issues. Similarly, management of the development process depends on transparent governance arrangements and bad governance is considered to be the root of underdevelopment. As the SDGs are aiming to leave no one behind, a careful rethinking is required.

Over two days in July, researchers from around the world gathered in Leicester and pondered how the SDG vision can be taken forward so that no one is left behind. This publication presents a summary of the conference and offers a compilation of the papers presented in various sessions. Other presentation materials (such as videos, photos and presentation slides) will be available from the conference website.

Papers included in the publication have undergone a light touch review and although an attempt has been to harmonise the style by adopting a common template, some deviations remain. The final versions of the papers as submitted by the authors have been included here. They have not undergone any language editing.

We would love to receive any comments, suggestions and feedback on this publication. You can send them to the editor of the proceedings (subhesb@dmu.ac.uk).

I hope you will enjoy reading this publication.

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Table of contents

Description	Page
Acknowledgements	2
Foreword	3
Conference summary	8
Papers from Session 1: SDGs and the cities	22
Integrating the SDGs into Urban Climate Plans: Insights from Japan, Eric Zusman, Ryoko Nakano, Matthew Hengensbaugh, Tetsuro Yoshida, Fernando Ortiz-Moya, Institute for Global Environment Strategies (IGES), Japan	23
Analysing climate action plans of selected UK cities for the SDG alignment, Subhes Bhattacharyya, Birgit Painter and Leticia Ozawa-Meida, IESD, DMU	45
Papers from Session 2: Energy Access and the SDGs	60
Experiences from solar PV rural businesses in Malawi, Damien Frame, Peter Dauenhauer, Aran Eales, Stuart Galloway, <i>University of Strathclyde, UK</i>	61
Overcoming the bottleneck of weak grids: Reaching higher tiers of electrification with SHS for increased supply reliability, Martha Hoffmann, Setu Pelz, Philipp Blechinger, Reiner Lemoine Institute, Berlin/Germany	76
Maximizing the penetration levels of hybrid renewable energy systems in rural areas with demand side management approaches in achieving SDGs, Lanre Olatomiwa and Richard Blanchard, Loughborough University, UK.	88
Policy coherence to enable effective energy strategies and promote sustainable development: toward developing an integrated simulation model for Nigeria, Adedoyin Adeleke, Fabio Riva, Francesco Tonini, Emanuela Colombo, Politecnico di Milano - Department of Energy.	100
Posters from the poster session	110
	113
Papers from Session 3: Urban architecture and the SDGs	
Circular economy in architectural design as a contribution to reach the SDGs goals. Processes, opportunities and strategies of C&D urban processes, Massimiliano Condotta and Elisa Zatta, Università IUAV di Venezia, Italy.	114
Vernacular architecture as a resource for resilient communities, Codina Elena	126

Dusoiu and Tana Nicoleta Lascu, UAUIM, Romania.

Solar and geothermal energy for low-carbon space heating and energy independence, Evangelos I. Sakellariou, Andrew J. Wright, Muyiwa A. Oyinlola, IESD. 141

Papers from Session 4: Renewables energies and the SDG 153

Effect of a closed loop cooling system upon the electrical output of solar photovoltaics (PV) panels, Rick Greenough, IESD. 154

Biomass energy potential in rural communities, Bruno Medeiros Coelho; Dionízio Paschoareli Júnior, UNESP, Brazil. 163

Integrating solar to ground seasonal heat storage for the small domestic heating sector in the UK: Experiments from a research prototype, Carlos Naranjo-Mendoza; Richard M. Greenough; Andrew J. Wright, IESD. 176

Papers from Session 5: Water and health issues in developing countries 185

Barriers to Monitoring Water and Sanitation delivery by NGO's: Case Study Ghana, Hikima Jewu, Health and Life Sciences, DMU. 186

Sustainable development and water conservation practices in South Africa, Djiby Thiam, University of Cape Town, South Africa. 198

Achieving sustainable development goals with an R&D prize platform for neglected diseases, Brigitte Granville (UCL) and Eshref Trushin, (DMU). 215

Papers from Session 6: Presentations from a distance 224

Energy Access through cross-border electricity trade: Pathway to Achieve SDGs in South Asia, Rohit Magotra, Shababa Haque, Asha Kaushik, Jyoti K. Parikh, IRADE, India. 225

What determines uptake of modern fuel: A case study of India, Pooja Sankhyayan and Shyamasree Dasgupta, Indian Institute of Technology, Mandi, India. 237

Analysis of Brazil's funding structure designed to meet the Sustainable Development Goal 7 targets, Clarice Ferraz, University of Rio de Janeiro, Brazil. 246

Papers from Session 7: Tools and evaluations 257

Are we lost in the ocean of human development? Finding our way through a SUSTAINABILITY COMPASS 258

Dr. Maurizio Sajeve, Marjo Maidell, Matti Valonen, Pellervo Economic Research PTT, Helsinki, Finland and Prof. Mark Lemon and Dr. Andrew Mitchell, Institute of Energy and Sustainable Development, De Montfort University, UK

Is this working? Evaluating solutions for sustainable communities, Andrew Mitchell, Mark Lemon and Andrew Reeves (IESD)	277
A survey informed propositions for identification, salience and co-option of stakeholders for steering the SDGs in Sub-Saharan African Countries, Muhammad Abubakar (IESD).	288
Papers from Session 8: Business solutions to address the SDGs	307
Women centred empowerment: developing solutions to improve living conditions in rural Mexico, Wastling, T., Sebastiampillai, S. , Liemberger, M., Dubreuil, X., Escamilla Greenham, P. , Mrzilek, J., Okpala, E. , Xue, J., Villa, R., Simms, N. and Encinas-Oropesa, A, (Cranfield and DMU).	308
Assessing the feasibility of solar micro-grid social enterprises as an appropriate delivery model for achieving SDG7, <i>Aran Eales, Scott Strachan, Damien Frame, Stuart Galloway</i> , Strathclyde University.	320
Aggregators - A proposal to make distributed generation in RURAL settlements PROFITABLE, Mariana Costa Falcão; João carlos Pelicer Jr ; Luiz Otavio Manhani Machado ; Dionízio Paschoareli Júnior (presented by Bruno Medeiros UNESP), Brazil.	332
Appendix 1: Conference Programme	338
Appendix 2: List of participants	343
Appendix 3: Post-event evaluation feedback	345

Conference summary

On 4th and 5th of July 2019, the international conference on Energising the Sustainable Development Goals through appropriate technology and governance was held in the Queens Building of De Montfort University, Leicester. The conference agenda is available at Appendix 1. The event was attended by around 80 participants from different parts of the world, including some via web-conferencing (Appendix 2 gives the list of participants).



The conference was opened by Prof. Subhes Bhattacharyya of the Institute of Energy and Sustainable Development (IESD). He explained that IESD has been involved in promoting sustainable development since its inception three decades ago through its systems thinking approach. The launch of the Sustainable Development Goals has provided an opportunity to take this work further to support the global transformation agenda. In line with this thinking, the purpose of the workshop is to explore how research can contribute to support the sustainable development goals so that the targets can be achieved over a period of a decade or so. De Montfort University is actively involved in promoting the global goals and it has been designated as the Global Hub for Goal 16. DMU has taken a strategic decision to embed the SDGs in all of its academic and research activities. The conference is aligned with this strategic vision of the university. He requested all the participants to consider how their work could help implement the SDGs and make the world a better place.

The keynote speech was given by Mr. David Kester, ex-CEO of the UK Design Council, and Founder of Design Thinkers Academy London and consultancy DK&A. He described how a design-led approach to technology is helping companies like software giant SAP and its global clients develop new systems for addressing Sustainable Development Goals.



The talk focused on the relevance of a designer in the context of the SDGs and explained this through a case study. He then offered five takeaways from the talk. The first part of the talk focused on human behaviour and asked how we can energise the SDGs by learning how individuals make decisions. He referred to the seminal work of Daniel Kahneman (*Thinking, fast and slow* – Nobel Prize winner of 2002 in Economics) and mentioned two parts of our brain system – the limbic side that makes instantaneous or automatic decisions and the cognitive side that follows a deductive or logical thinking process. Facing a change in the condition of our life or the surrounding around us, as human beings, our brain reacts naturally and instantaneously to the change but we need to learn how to overcome the resistance to change. While the natural resources are limited, the human behaviour and ingenuity is unlimited and this resource can be tapped to drive the change. The examples of Wikipedia, World Wide Web, AirBnB and others are all innovative ideas that take imagination to a new level and influence human behaviour.

He then presented a case study of a design innovation project around plastic wastes. Worldwide, 1 million bottles are bought per minute and 8 million tons per year end up in the oceans. The SAP project on reducing plastic use in the supply chain was to identify swift, impactful and systemic solutions given the current appetite for change in the use of plastics. The work involved co-creation through an engagement with people where individual and group behaviour around plastic use led to different behaviour prototypes. The second level of engagement was with the supply chain stakeholders to develop solutions to support the process of change. The companies worked collaboratively and in association with the consumers to develop tools to empower the behaviour change. The presentation offered a few examples (a new mug for Costa Coffee, real time analytics of plastic lifecycle) of innovative ideas that were produced by the SAP project. The global companies could roll out the innovations in nine months - from concept to implementation in scale.

The talk ended with five key lessons:

- 1) Co-create with all the relevant stakeholders;
- 2) Develop systems with your users;
- 3) Let the purpose and people drive;
- 4) Follow a good design process
- 5) Be the optimistic future

The keynote speech offered an optimistic perspective about the future and perfectly blended the technological options with human behaviour. This relates to the governance aspects and appropriate technology focus of the conference very well.

After the tea break, two parallel sessions took place. Session 1 focused on the SDGs and the cities while Session 2 was devoted to energy access and the SDGs. Dr. Andrew Mitchell of IESD chaired the first session while Dr. Rupert Gammon chaired the second session.

Three presentations were made in **Session 1**. This session reported the research activities being carried out as part of the ESRC-funded research project (ES/S013547/1) - Integrating the sustainable development goals into climate planning in British and Japanese cities. The first presentation was made by Dr. Eric Zusman of the Institute for Global Environmental Strategies (IGES), Japan who shared the work being carried out in Japan by IGES on the climate action plans of Japanese cities. His presentation focused on a governance framework arrived at from a review of the literature that was used to explore the integration of the SDGs in the climate action plan of two cities, namely Kyoto and Matsumoto. The study suggested that integration of the SDGs can be advantageous for cities in dealing with the issue of climate change but a conscious effort is required to achieve such an integration. Dr. Leticia Ozawa- Meida presented the second paper focusing on the climate action of UK cities. This study considered the regulatory and policy environment in the UK relating to climate action in cities and adopted a text analysis approach to understand the areas of focus in the city plans. The plans of three cities, namely Leicester, Bristol and Milton Keynes were reviewed using the text analysis approach and the comparative picture was highlighted. An attempt was then made to map the linkage between SDG13 (climate action) on other SDGs using Bristol's city level SDG targets as an example. Given the recent genesis of the SDGs, it was found that most of the existing city climate action plans did not explicitly consider the SDGs and their focus was mainly on energy use in the city. The third presentation was made by Dr. Fernando Ortiz-Moya of IGES about the initiatives in Japanese cities to integrate urban metabolism concepts to integrate the SDGs at the local level. The idea emphasises living in harmony with the nature but encourage the local communities to use of local resources for economic activities. The concept is being promoted to support rural-urban nexus, ecosystem based solutions, circular economy principles and zero/ low carbon communities in Japan.

A discussion followed after the presentations. There were specific questions to presenters and there were a few general queries and comments. There was a question about the criteria used for selecting the cities that were selected from the UK. Dr. Ozawa-Meida replied that the choice was based on convenience sampling and access to reliable data. She was also asked with respect to text analysis and word counting, how does the analysis address issues like synonyms and other ways of talking about the same issue even though different language may be used? She replied that the word frequency work was done using Nvivo and while some effort was made to explore

and account for synonyms, this stage of the work was preliminary and only intended as a first step.

There was a question about the concept of ‘urban metabolism’. Given the strong emphasis on organic/ biological processes, what was the origin of the term and how does it shape the way we think? Dr. Ortiz-Moya replied that the concept dates to the 1960s as a framework for what was happening in the cities, specifically looking at inputs and wastes. Broadly, it is similar to the idea of a circular economy, and examines the flows of energy and materials within a system.

An observation was made that much of the work described refers to a top down design process without including citizens and other participants. Are there key skills required to help actors participate (e.g., systemic thinking, transdisciplinary skills, etc.)? Dr. Zusman replied that it requires less of a skill set as such, but more of an attitude or inclination and a willingness to learn and to suspend technical vocabulary in order to be inclusive.

There was a question on the role of children given that it is their future and so they are likely to be serious stakeholders in homes and in schools. Dr. Zusman replied that sustainable behaviour takes root very early on, especially in Japan, with a strong emphasis on harmony between humans and nature, even for very young children (e.g. food sources and nutritional values). These become the norms and ideational factors that lock us into behaviours just as much as institutions and infrastructure. Dr. Ozawa-Meida noted that although while this was not addressed in the current paper, IESD has been, and continues to be, involved in several projects that involve schools, such as, Eco-Schools, E-Teacher

There was also a query about the form of interventions – for example, compulsory or voluntary – with respect to furthering the climate agreements. Dr. Zusman replied that some of the climate agreements endorse mandatory compliance with targets, so this is quite a top down approach. However, this has shifted to a more voluntary approach in order to bring in developing nations who did not want to sign up to targets and monitoring regimes which would have not been in their own developmental favour.

The audio recording of the session can be found here: <https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=0f5d303b-6baf-4e4b-9c5f-ef087ca1459e>

Session 2 on energy access and the SDGs was chaired by Dr. Rupert Gammon of IESD. Four presentations were made in this session. Prof. Stewart Galloway of University of Strathclyde presented the feasibility of micro-grid social enterprises as a suitable delivery model for supporting the SDG 7. For this purpose, the characteristics of a social enterprise to deliver solar micro-grids. Then a framework is presented to evaluate the financial viability and social impact of such an enterprise. The talk outlined five features of a social enterprise: social purpose, engagement in the marketplace, reinvestment of profits, community engagement and participation and organisational accountability. For assessing the financial viability, the paper suggests a pre-assessment exercise to avoid commitment of resources unless the basic conditions are favourable to a micro-grid business. If the initial assessment suggests a positive outlook, further investigation through market assessment and a site-specific feasibility study is required. If the business proposition looks feasible, a suitable business model with plans for scaling-up has

to be developed. To evaluate the social impact of a micro-grid social enterprise, a framework using key performance indicators is suggested. Through a set of indicators such as uptake of productive load, or impact on gender, education and health can be monitored against set targets at different milestones. This can help monitor and evaluate the performance of the intervention.

Ms Martha Hoffmann of Reiner Lemoine Institute of Berlin (Germany) in her presentation explored the potential of solar home systems (SHS) to ensure reliable electricity supply for households using a case study in Nepal. The grid supply is unreliable in many places and the purpose of the work was to investigate if SHS can play a role in improving the service. For this an extensive survey in 14 municipalities of Kathmandu was undertaken to understand the demand, appliance use behaviour and the willingness to pay. The consumer profile is dominated by low demand users (Tier 2 as per the Multi-tier Framework) while only a small segment of the user comes under Tier 4 (high end use). A system modelling was carried out considering different technology options (grid, off-grid SHS, back-up battery, and back-up SHS) with AC and DC load configurations. The study found that the grid supply is the least cost solution but it is unreliable. Off-grid SHS is not cost effective but SHSs as a back-up to the grid comes as a viable option that can ensure reliability of supply and meet the demand. The study therefore calls for going beyond the grid-off-grid dichotomy to support an integrated development to support energy access in countries like Nepal.

The third presentation was made by Dr. Richard Blanchard of Loughborough University. He presented a case study of rural hospital in Nigeria for which they investigated the feasibility of a hybrid renewable energy system to meet its electricity needs. The innovative idea of the study was to consider demand-side management (DSM) options to improve the viability of the project. The study assessed the load of the hospital, performed the techno-economic analysis of the hybrid energy supply system, developed DSM strategies and updated the system configuration considering DSM implementation strategy. The case was simulated using HOMER and it found that the DSM strategy reduces the cost of supply of electricity, cost of investment and reduces environmental effects. It shows the interlinkages of electricity access with other SDGs, namely SDG13 and SDG 3 (health).

The fourth presentation of this session, made by Mr. Adedoyin Adeleke of Politecnico di Milano, focused on a systems dynamics-based modelling exercise to analyse the interlinkages between the SDGs considering the case of energy access in Nigeria. The effect of integration of renewable energies in the energy mix on energy consumption and GDP was captured through a causal loop diagram. This was then converted to a systems dynamics model to simulate the long-term effect of various renewable energy policies on energy access, economy and social welfare (health and education). Data from 1990 to 2015 was used to calibrate the model. The paper reported working in progress and only preliminary calibration effort was reported in the work. However, the tool, once fully calibrated and operational, will be able to capture the effects of energy development scenarios on different challenges highlighted by the SDGs and will be able to identify the complimentary actions required to support sustainable development in Nigeria.

At the lunch time, delegates had the opportunity to network. There was a poster session as well where doctoral students presented their work. Ms Asma Alahmed of University of Sheffield presented her poster titled 'How can technology support the learning in developing countries?' Ms Paloma Ortega Arriaga of Imperial College London presented a poster titled Rural

Electrification Strategies to address Energy Access and Climate Change. Sheridan Few of Imperial College presented a poster on RENGA project: Resilient Electricity Networks for a productive Grid Architecture.

The third session on urban systems and the SDGs was chaired by Dr. Adriana Massidda of the Institute of Architecture, DMU. The session focused on architectural design and how specific elements and can contribute to support the Sustainable Development Goals agenda.

The first paper, by Massimiliano Condotta and Elisa Zatta (Università IUAV di Venezia, Italy), focused on material re-utilisation and what it means for construction practice in the present day. In fact, even though human construction has reutilised materials since ancient times, the recycling and re-deployment of materials presents a promising contribution to several SDGs – specifically SDG 9 (in particular 9.4), SDG 12 (12.2, 12.4, and 12.5) as well as SDG 11 (11.4 and 11.6), the latter going beyond materiality itself and related to preserving the cultural fabric. The paper highlighted the different stages necessary to achieve this, a few contemporary examples of good practice, as well as the foreseeable obstacles. Amongst the latter some key challenges related to legal regulations and benchmarking, difficulties in locating the materials, and also low motivation in both stakeholders and the general public.

The second paper, presented by Tana Nicoleta Lascu and co-authored by Codina Elena Dusoiu (UAUIM, Romania) focused on vernacular practices and highlighted a series of elements that could be of use in attaining the SDGs. For each element, a few vernacular and contemporary examples were shown, and its advantages and drawbacks were highlighted. Elements included green walls, green roofs, inner courtyards (inspired in Spain's *patio andaluz*) and buffer spaces such as verandas.

The third paper, presented by Evangelos I. Sakellariou and co-authored by Andrew Wright and Muiyiwa (IESD), summarised the findings of the testing of PVT panels, recently-designed by the team. The measurements were conducted in Birmingham, UK, and involved comparison between a new and a retrofitted house, varying the amount of PVTs used and assessing the impact of that variation. The results detailed findings for balancing heat and electricity consumption, and compared them to the use of natural gas. PVT panels support SDGs 7, 13 and especially 11, and are easily adaptable to various climates.

The discussion was lively, with intervention from several members of the public and thorough responses by the speakers.

The audio recording of this session can be found here: <https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=4208582d-a608-4a79-b0f2-8d6b90319a04>

Session 4 on Renewable energies and the SDGs was chaired by Dr. Richard Snape of IESD. This session had two presentations – the third presenter from Brazil was in Leicester but could not participate due to illness. In his presentation Professor Rick Greenough of IESD presented a study of the effect of forced cooling on the output from photovoltaic-thermal solar panels. He presented the results from an experimental work carried out in a retrofitted terrace house in

Leicester. Six PV-thermal panels and one PV panel without cooling were installed and the performance was compared over a four year period. The results show that the solar thermal system underperforms by 3% compared to the PV system. The PV-thermal system performs better during summer and could work better in warmer climates if the heat can be effectively removed and used for other purposes.

The second presentation by Mr Carlos Naranjo-Mendoza of IESD shared the results of an experimental work of solar-assisted ground source heat pump. The demonstration experiment was carried out in Leicester and used shallow boreholes to supply heating to a small domestic dwelling. The system consisted of 16 boreholes of 1.5m deep connected in series and are supported by seven PV- thermal solar panels. The ground heat exchanger, located in an earth energy bank near the house, is connected to a ground source heat pump that provides heating energy to the house through an underfloor heating system. The study reports data for 19 months and shows that the system can meet the heating needs of a low-energy home. It was suggested that this type of heating system could be cost competitive with electric heating and can even be cost effective when used with a smart control system. There is a significant potential of adopting such a technology to support a transition to a low carbon heating pathway in England, which contributes to the SDG 7 target.

Session 5 was chaired by Dr. Kutoma Wakunuma of the Centre for Computing and SR (DMU) which focused on water and health issues in developing countries. This session had three presentations. The first presentation was made by Ms Hikima Jewu of DMU who discussed the barriers to monitoring water and sanitation delivery by NGOs in Ghana. Ghana depends heavily on NGOs for providing water, sanitation and hygiene related services but many of these initiatives become non-operational within 5 years of their launch. The study tried to uncover the challenges that are affecting the effectiveness of these services offered by NGOs. Using primary data from five districts collected through semi-structured interviews, the study identified several factors such as corruption, bureaucracy, lack of funding support, lack of monitoring and local culture that have contributed to the poor performance. The study also suggests that more attention is required for implementation, monitoring and evaluation of project activities to overcome the challenges.

Dr. Eshref Trushin of DMU Business School presented his work on an alternative platform for medicine innovation in developing countries. There are 50 neglected diseases that do not receive R&D attention of large companies due to small market potential, although a few million people die world wide and about 3 billion people are at risk of adverse effects. The study proposes a new incentive model to support R&D for medicine development for neglected diseases. The proposed system uses a non-profit open platform that allows knowledge sharing and networking. The platform can be funded through crowd funding, subscription fees and selling priority review vouchers for new drugs. Innovators propose drugs but the R&D cost is delinked from drug price. A crowd of experts and volunteers decides the winners and they receive two prizes – one if the drug is selected for clinical trial and the second payment is in proportion to the drug quality. The proposed system aims to create a self-sustaining innovation ecosystem with the desirable features. This way it can overcome the challenges faced by neglected diseases and contribute to different SDGs (1, 2, 4, 10, 11, 16 and 17).

The third presentation was about water scarcity in South Africa and investigated the factors that drive adoption of water conservation measures in urban settlements. It also tries to find out whether the publicity about water scarcity could be used as an intervention to influence conservation behaviour. The study used an economic model to develop a theoretical understanding and then tested it using survey data from 465 households. A range of water saving options (rainwater bucket, greywater bucket, water tank, pond, borehole, etc.). The study found that publicity and information provision positively affect conservation behaviour. Depletion of freshwater reserves is influencing conservation behaviour of residents. However, the drivers of specific user behaviour is not well understood.

The audio recording of the session can be found here:

- a) First presentation -
<https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=cda0bd7d-e944-45d2-a0ad-4335ce67f374>
- b) Second presentation:
<https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=35474593-7f32-4fd9-8389-ffac8fd23411>
- c) Third presentation
<https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=3691eb24-fea7-4405-bd40-f446454b2950>

In the afternoon, a panel discussion was organised which was moderated by Professor Subhes Bhattacharyya of IESD. The questions that were posed to the panel are: What is appropriate technology in the context of sustainable development? What is appropriate governance? Do they depend on the context and if so, how can they change? What are the factors or parameters that could influence the technology and governance choice? What is the level of interaction at different levels of governance and how could the interaction be facilitated? The panel consisted of Prof. Mark Lemon of IESD, Prof. Richard Werner of Leicester Castle Business School, Dr. Eric Zusman of IGES, and Dr. Maurizio Sajeve from Finland. The discussion opened by reminding that the idea of an appropriate technology was discussed in the 1970s when large companies from the developed world started taking their technology to the developing world to solve a given problem and often involved creating a market for their own technology and implanting it in the developing world. However, this did not consider the alignment with the socio-economic context prevailing locally and just focused on the technical element alone. An appropriate technology has to be aligned with the local context to meet the needs of the local people but without damaging the local ecology or ecosystem. A panellist remarked that although technology was often introduced to address a particular problem, it caused greater problems in the end. We focus on getting things done but we do not have full knowledge about the consequences or impacts that may come in the future and a precautionary principle is better to follow. The panel's view was sought on the issue of technology being a solution to our developmental ills when the technology is perhaps reducing social connections and affecting the traditional knowledge that communities and societies used to pass on through generations. How can developing countries avoid the pitfalls of the technological paths that developed countries followed and become more resilient? A panellist responded that there was the power dimension in all technology transfer arrangements and despite the intentions, many arrangements increased

dependency, and did not lead to sustainability. The need for decentralised solutions was highlighted because this allows more democratic solutions and reduces power equation. The way locals view nature can vary from one area to another and the relationship with the nature and how this is affected through technology depends on the attitude of the community and its willingness to take risks. This interaction, attitude and willingness to adapt at the local level is crucial for sustainable development. Another panellist suggested that there is a wrong perspective that technology can solve everything. Following nature and avoiding going against the natural cycles will be a more appropriate approach. Learning from the locals is also important.

A panelist remarked that technology may not be the right word – it may be better to focus on solutions. Some of the best ways to harness solutions are to find new ways to work together and such participation does not necessarily have to rely on democracy. Expert-based system with some participation has been adopted in several countries (China, Bhutan). There are different systems that deliver and they need not always conform to the western idea of democracy. An example of absolute monarchy was given but this country is more democratic than any other country in Europe due to its smallness. However, the linkage between decentralised decision-making with the bigger picture and a larger-scale of issues is not clear and the appropriate level of governance requires more research. There is no one-size-fits-all governance arrangement and it is important to involve a random sample of people for decision making. This can be closer to the ordinary people and make it relevant for the society. The institutions also need to be set such that they are insulated from politics to some degree and they are embedded in the larger social structure but outside the influence of vested interests. A question was asked about the compatibility of the goal of economic growth (SDG 8) with strong institutions. There was a debate on this idea of economic growth and what it means. Lifting people out of poverty and improving the quality of life is an important issue but the concept of economic growth ignores other capitals (social, environmental, etc.) and there is wider scope for potential growth in these areas to support sustainable development.

Supporting the SDG would require a process of governance that may vary depending on the context but a facilitative arrangement at different levels would be essential. A dialogue in the society is essential given so that a relevant approach can be adopted.

The audio record of the panel discussion can be found here: <https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=fafb6b9e-48b2-404a-aced-92678eedf023>

Session 6 was organised to facilitate the participation of delegates who could not join the conference physically. This was an effort to reduce carbon footprint of conference participation, which aligns well with the conference objectives. The session was chaired by Dr. Andrew Reeves of IESD who arranged the live session using Blackboard Collaborate. Three participants presented their work- two from India and one from Brazil. The first presentation by Ms Pooja Sankhyayan of Indian Institute of Technology, Mandi (India) considered the determinants of modern fuel uptake in India, with an emphasis on electricity and LPG. The main research questions were to find out how expensive the transition is from traditional energies to modern fuels and what factors determine the access to these fuels in India. The work found that the

transition from traditional energies to LPG involves a 9 fold increase in fuel bills for the households whereas the shift from incandescent light to compact fluorescent light involves a minor change. An econometric analysis of National Sample Survey data was used to identify the determinants of LPG and electricity access. It was found that 1) infrastructure creation leads to better electricity access but the same does not hold for the LPG access; 2) price plays a limited role in explaining the access level and 3) per capita income has a significant influence on the access and 4) literacy and women empowerment helps modern fuel uptake.

The second presentation, by Dr. Rohit Magotra and Ms Asha Kaushik of IRADe (Integrated Research and Action for Development, Delhi), looked at the issue of cross-border trade in electricity to support energy access in South Asia. The study considered the electricity trade between India and Bangladesh that began in 2013 and explored the socio-economic impact of electricity trade on the lives of previously electricity deprived population. Primary data collected through surveys and focus groups held in two villages near the entry point of imported electricity formed the basis of the study. The results show that cross-broder electricity trade and subsequent electrification of the villages have generated wider socio-economic benefits at the micro level. Access to electricity has contributed to better education, better income generation opportunities, women empowerment and better infrastructure. They have contributed to increased mobility, better value for land, better communication facilities and other services such as access to clean water, and refrigeration. Consequently, improvement in respect of several SDGs was possible. The benefits of such trade at the local level could be appreciated from the study.

The third presentation by Dr. Clarice Ferraz of Federal University of Rio de Janeiro investigated the funding structure in Brazil to meet the targets of SDG7. Brazil has specified its targets for SDG7 in its Nationally Determined Contribution and aims to reduce carbon emissions by 43% compared to 2005 baseline and reach a 45% renewable energy share by 2030. For energy efficiency, the NDC has adopted a modest improvement of 10% in the electricity sector, which is not aligned with the requirement of doubling energy efficiency improvements in all sectors of the economy. The presentation reported work-in-progress and suggested that Brazil is likely to reach the objective of universal energy access target but affordability of energy can be an issue for the users. It is also likely to reach the renewable energy target but there are concerns about energy efficiency and rationalisation of fossil fuel subsidies in the country. The energy efficiency has to improve at a much faster rate but this area remains underfunded. Moreover, there is no sign of reducing the fossil fuel subsidies and the government has extended the tax exemption to oil and gas industry until 2040. The new administration is turning away from the sustainable development agenda and without funding support and international cooperation, Brazil will have significant challenges in reaching its SDG targets.

The audience clearly enjoyed the presentations and the webcasting worked quite well. The participants were moved by the recent developments in Brazil, a country that has hosted the major events on Sustainable Development and has actively participated in taking the agenda forward until recently. Lack of political support and reversal of policies will adversely affect the progress towards sustainable development.

The audio recording of the session can be found here: <https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=d6673c02-f438-48f8-b5db-e0a8976dc6a8>

Professor Rick Greenough of IESD chaired **Session 7** which focused on tools and evaluations. Three presentations were made in this session. Dr. Maurizio Sajevea of Pallervo Economic Research (Finland) presented his work on sustainability compass, which is a model and a practical tool to support decision-making in the context of sustainable development, particularly through better governance and innovation. The participatory and game-based structure of the tool was introduced and its development through the interaction with the Finnish industry (agro-food, wood-based materials, and renewable energies) was elaborated. The sustainability compass is designed to support innovation at two stages: innovation design and innovation adoption. Stakeholder participation at the initial stage is used to map the activities of specific innovative industries or sectors onto the SDGs. This also leads to potential themes and indicators and these are further discussed with the stakeholders in a second workshop. On the basis of these interactions, a provisional tool-kit for the sustainability compass is developed. The presentation was a precursor to the workshop scheduled for the afternoon of 5th July.

The second presentation by Dr. Andrew Mitchell of IESD discussed the issue of evaluating complex community interventions and considered how the lessons from such interventions could support the implementation of the SDGs. Through a case study of Sustainable Harborough project, the work explained how alternative approaches were used to evaluate different aspects of the project. The local economic impact of the project was evaluated using the Local Multiplier to the 3rd round (LM3 approach). This tested the assumption that supporting local businesses benefits the local community. The Social Network Approach was used to evaluate the ability of the network to absorb shock without changing state (network resilience). Stakeholder input was used to capture project learning and the data was analysed thematically and statistically. This led to three main learnings: 1) develop and sustain trust with key stakeholders over time; 2) develop and maintain networks with strong and weak ties; 3) Embed processes for reflection and evaluation to inform action planning. Based on the finding of this study, the following guidance can be given for the SDGs: 1) learning must be scaleable and transferable; 2) rapid evaluations of impact are essential to inform the strategy; and 3) strategies have to be adaptive and scenario-based.

The third presentation by Muhammad Abubakar of IESD asked about the perspectives (appreciation, aspirations and appetite) of stakeholders on SDG7 in Sub-Saharan Africa. The analysis was conceptualised as complex system problem and an iterative evolutionary was relied on. Three rounds of interactions with 12 expert panelists from Nigeria formed the basis of the work. The study found that the need for more emphasis on customised (localised) SDG approaches has become apparent. However, the stakeholder perspectives remain divergent and adequately co-opting various stakeholders and their perspective could be the key for timely hitting the SDG targets.

The audio recording of the session can be found here: <https://dmureplay.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=40b5e199-b587-40a8-8694-290eaf4cc04e>

Session 8 on business solutions to address the SDGs was chaired by Prof. David Rae. Director of the Centre for Enterprise and Innovation at Leicester Castle Business School, DMU. Two

presentations were made at this session and the third presenter could not join the session due to illness. Professor Stuart Galloway of University of Strathclyde talked about the experience of solar PV business in Malawi. He described the Sustainable Off-Grid Electrification of Rural Villages (SOGERV) Project that ran between 2015 and 2018. He also discussed the monitoring and evaluation of the project. The experiences of solar energy business in Malawi. As part of a Scottish Government funded project, the University team was working on a project to support community-based solar energy businesses that can benefit from solar charging stations set up in the communities. The presentation highlighted two main areas: market assessment during the initiation phase and the analysis of financial data during the operational phase of the project. The market assessment involved surveying households and businesses to understand their level of interest in energy services and the perception of affordability and profitability of these activities. Due to relatively low income of the local population, limited cash sales will be possible and a financing arrangement will be required to support solar energy products. But the businesses thought that the services will be profitable if the market is rightly targeted. During the operational phase, it was found that the appetite for larger products was more than expected but it was harder to establish the demand for productive use of energy.

Dr. Raffaella Villa of DMU presented a paper on behalf of co-authors presented a work about women empowerment through the development of simple and sustainable solutions to support living condition of local people in a Mexican community. The project was undertaken in Jaltepec community of San José del Rincón located in the Western part of the State of Mexico. A human-centred design framework was developed to understand the problem, co-create the solutions with the local community and identify the most appropriate solutions for implementation. Two main issues – indoor air pollution and unsafe drinking water were identified for intervention. A simple water filter using sand filtration and cloth filtration was designed and lab-tested to evaluate its effectiveness in reducing turbidity. To reduce indoor air pollution, an improved design of the locally built cookstove was prepared. To carry resources (like water from the source in the local terrain), a cart was designed that can be built locally. These simple interventions were designed considering local skills and expertise and to support women in the community. By reducing exposure to pollution and unsafe water, they improve the quality of life and health. The cart reduces burden of carrying water and other heavy items over a distance and contributes to better living.

The conference formally ended after lunch but the second half of the second day was reserved for the Sustainability Compass Workshop. This was facilitated by Dr. Maurizio Sajeve with the support of Prof. Mark Lemon and Dr. Andrew Mitchell. Around 20 participants joined the workshop and followed the three step process discussed in Dr. Sajeve's presentation in the morning.

A post-event feedback survey was done by sending a questionnaire via Survey Monkey. 16 participants responded to the survey and 44% of them found the event excellent while another 38% considered it very good (see Fig. S1). More than 80% of the respondents thought that the event was very well organised (Fig. S2) and the staff were very helpful. Additional comments and suggestions on the conference are presented in Appendix 3.

Fig. S1: Survey response about the event

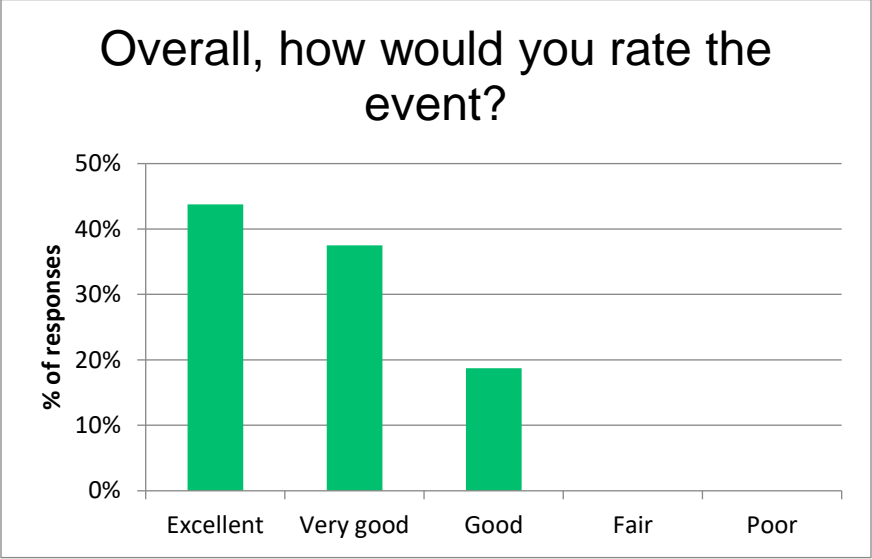
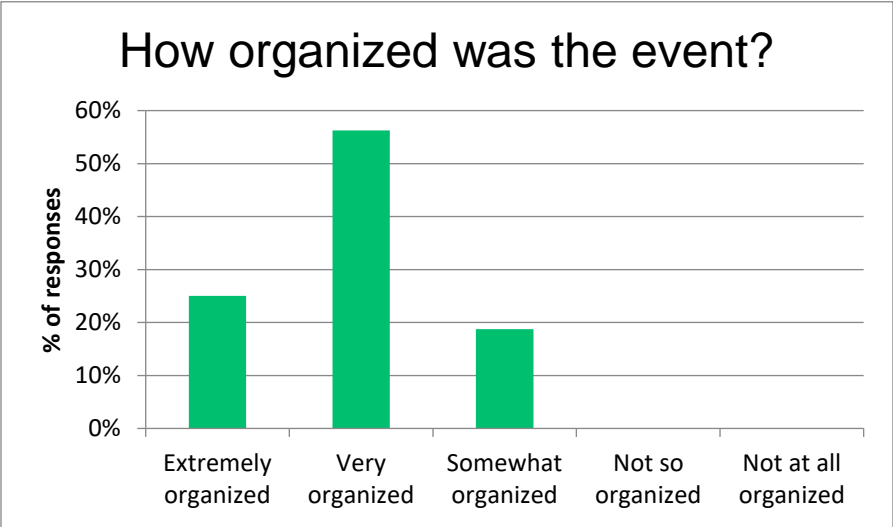


Fig. S2: Feedback on conference organisation



The Sustainable Development Goals offer an opportunity to think about developmental issues in an integrated way. The call for leaving no one behind is a powerful message but achieving this objective requires coordinated actions at different levels and scales. The bottom-up, local level initiatives as suggested in various presentations are important in setting the agenda in motion but scaling them up at the national and global level will be required to share the benefits widely and making the world a better place for all. The research discussed in the conference has captured a range of areas, including city climate action plans, energy and rural development, health, water, sanitation issues as well as evaluation and monitoring of progress with the SDGs. The interactions allowed the participants to gain different perspectives and appreciate the challenges better.

The key takeaway points from the conference are:

- 1) Energising the SDGs require a design thinking approach that takes advantage of the ingenuity of ordinary people in solving the problem but uses the expertise and skills of the industry, bureaucracy and the society to turn these into scaleable solutions that can reach a wider section of the population quickly. If the goals have to be reached, actions need to be taken on a war footing.
- 2) The decentralisation of the decision-making process by empowering the users and the beneficiaries can facilitate the adoption of sustainable solutions at the local level but a multi-level governance arrangement to facilitate the implementation of the agenda at scale is crucial to deliver the goals globally.
- 3) The research reported here and discussed at the conference offers useful insights from individual projects and more research is required to inform policies and designs for the future.



Papers from Session 1:

SDGs and the Cities

Integrating the Sustainable Development Goals into Urban Climate Plans: Insights from Japan

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Key Messages

- **Cities can derive important advantages from aligning urban climate change plans with sustainable development priorities defined under the Sustainable Development Goals (SDGs).**
- **Linking city climate plans with urban sustainability issues involves understanding ways to maximise synergies and manage trade-offs.**
- **Some of the more evident synergies and trade-offs are associated with water, waste and air pollution, employment and social inclusion, and investing in low-carbon, resilient infrastructure.**
- **Several factors may enhance or impede integration of climate and sustainability concerns, including supportive governance arrangements, participatory engagement mechanisms, and vested interests.**
- **By proposing an analytical framework, this paper seeks to assess the extent to which climate-SDG linkages are considered in Japanese cities, assessing potential areas for further integrating sustainability concerns into climate plans.**

1. Introduction

The world is urbanising rapidly. Not only do more than half the world's people live in urban areas, cities account for a fast-growing proportion of their economic development. Because cities are key drivers of such development, they engage in many activities that contribute to climate change. At the same time, the continued growth of greenhouse gases (GHGs) globally has made cities ever more susceptible to heat waves, flooding, intense storms and a litany of other adverse climate impacts. Both these growing contributions and expanding vulnerabilities have led many cities to formulate climate plans aimed at reducing GHGs as well as building resilience to the unwanted effects of a warming climate.

The adoption of climate change plans in cities is indeed a welcomed development. Cities typically possess the most intimate knowledge of how to make their energy infrastructure, transport systems, and built environment more climate-smart and resilient (Seto, Sánchez-Rodríguez, & Fragkias, 2010; Milner, Davies, & Wilkinson, 2012). Further, because they are often more flexible than national governments, city and municipal administrations can frequently introduce more innovative approaches to mitigating or adapting to climate change (Rosenzweig, Solecki, & Slosberg, 2006; Department for Environment, 2013). Finally-- and most central to this paper-- cities are ostensibly well-positioned to align their climate change plans with other sustainable development concerns, such as those covered under the Sustainable Development Goals (SDGs) (Shaw, Burch, Kristensen, Robinson, & Dale, 2014). For instance, cities could plan to ensure that efforts to save energy in transport simultaneously create jobs and address inequalities (Habitat, 2016).

There are many advantages to achieving coherence between urban climate plans and broader sustainability priorities. One such benefit is that can be more cost-effective to pursue multiple climate and development objectives as a single set of integrated issues as opposed to isolated policies and plans. A second strength is that potential conflicts between related policy areas—for example, job losses from a shift to renewable energy—can be anticipated and managed. A third possible benefit is that seemingly marginal environmental issues (such as provisions of green space) can be afforded more weight in decision-making processes. Last but not least, forging links between climate and other sustainability objectives is consistent with the letter and spirit of the Paris Agreement as well as the 2030 Agenda on Sustainable Development and its SDGs. Many national governments are hoping cities will move in this direction as they localise both of these agendas.

The above descriptions makes clear there are multiple advantages associated with ensuring that broader sustainability objectives run through urban plans targeting climate change. However, relatively little is known about the steps cities are taking to make climate plans sustainable. In fact, it remains largely an open question how and to what extent cities are making links between their climate and sustainability objectives. The primary aim of this paper is to develop an analytical framework which will help to assess whether these linkages are being made in several plans in Japan. A related objective is to identify possible factors that enable or undermine integration of sustainability concerns into climate plans in Japan.

The remainder of the paper is divided into four sections. The next section outlines some of the key relationships between climate and environmental, social and economic objectives. A third section describes some of the reasons that linkages may or may not be made between these objectives. A fourth section presents case studies—one for the

large city of Kyoto and the other for the smaller city of Matsumoto—to assess whether the outlined linkages can be found in climate change or other relevant plans. A final section concludes with some preliminary recommendations and suggestions for the way forward.

2. Sustainable Climate Planning in Cities

With more than half the world's population, cities will play a pivotal role in determining whether the world will realise its climate change goals. The recognition of cities' critical role is evident in relevant literature as well as the practices of a growing number of urban areas. Beginning in the 1990's with the support of emerging networks of local governments such as ICLEI, many cities began to embrace changes to their energy, transport, and waste management systems in an effort to reduce harmful emissions and safeguard residents from climate impacts. In recent years, the advent of the SDGs with its emphasis on integration across the multiple dimensions of sustainable development has opened opportunities to make connections between climate plans and local environmental, social and economic priorities. In fact, there are potentially quite a few synergies, and possible trade-offs, between efforts to address climate change and associated urban environmental, social, and economic issues. This section illustrates some of the more apparent points of overlap and conflict.

2.1 Climate and Environment Dimensions

An important set of interlinkages between the environment and climate change in cities involves water. Climate-induced changes in the biophysical environment--most notably droughts and flooding--are already placing heavy stresses on urban water systems with implications for both water quantity and quality (Szabo et al, 2016). To some extent, these strains can be countered by water efficiency measures and wastewater treatment programs. This is particularly true if such programmes account for the greater variability in temperature and precipitation (Dong and Hauschild 2017; Parkinson et al 2019). In other instances, it is changes in precipitation and temperature that lead to a far-reaching chain reaction of effects. Such is the case with the wide-ranging impacts of variable precipitation patterns and water scarcity on food systems; some have advocated for viewing these problems through a food-water-energy nexus to address interrelated challenges (Revi 2008; Rickien et al, 2017). Water-related impacts can also interact with other environmental resources. In cities with few parks and green spaces, for example, the lack of wetlands can effectively remove a set of natural buffers that would otherwise prevent flooding. Hence, in some cases solutions that explicitly factor in these interactions through nature-based adaptation in cities (Dorst, et al, 2019). In other instances, infrastructures such as permeable pavement can lower flood risks (Bai et al, 2018).

Some of the strongest climate-environment synergies are between climate change and environmental pollution, particularly air pollution. Because many of the sources of air pollution stem from the combustion of fossil fuels, they also contribute to greenhouse gas (GHGs) emissions. Policies and measures that can curtail energy use, then, deliver co-benefits--that is, benefits both for air quality and climate (Zusman et al, 2014). Co-benefits can be achieved from reductions in energy use in the transport, buildings, industrial, and many other energy-related sectors (Puppim de Oliveira et al, 2015). They can also be achieved through measures that target reductions in types of air pollutants that contribute to near-term climate changes known as short-lived climate pollutants (SLCPs). Measures that can abate SLCPs--such as particulate traps on diesel vehicles--also generate significant co-benefits (UNEP, 2011). Another area receiving critical attention for SLCP abatement includes improving municipal solid waste management systems, especially the quality of collection, treatment and disposal (Premakumara, et al, 2018). An additional set of benefits could involve urban forests; expanding forested areas and green spaces could not only cut air pollution levels but serve as a sink for absorbing GHGs in cities (Zhao et al. 2010; Baro et al 2014). There is an expansive literature estimating the size of these co-benefits, often with efforts to monetize a key set of social benefits in the form of health benefits (Puppim de Oliveira et al, 2015).

2.2 Climate and Social Dimensions

The clearest links between social dimensions of sustainability and climate change involve the potential employment impacts from climate and clean energy policies. Many such linkages involve green jobs--defined as the types of employment that optimise the use of energy and natural resources, reduce waste and pollution, and contribute to overall environmental conservation, while at the same time providing for decent, quality work (UNEP, 2008). Work on green jobs has underlined that while climate policies can contribute to employment creation in emerging sectors or the replacement of certain jobs in existing sectors, they can also lead to the elimination of some jobs (especially in energy-intensive and extractive industries) and redefinition of employment routines due to changes in associated skills profiles (UNEP, 2008). For many cities, then, making the most of the climate-employment dynamic will require at least a two-pronged approach. On the one hand, policymakers may aim to attract green jobs and industries. On the other, they may want to institute programmes that adapt to anticipated labour market disruptions by, for example, reskilling and upskilling workers through tailored technical vocational education and training (TVET) programmes (Pavlova, 2018).

An additional set of relationships involve the interactions between climate and demography and social equity. Even within relatively narrowly defined confines of a city the impacts of a changing climate are far from uniform. As a general rule, higher

temperatures and more intense storms tend to be more deeply felt by senior citizens, youth, and populations with less means (Haq et al, 2008; Li et al, 2016). This suggests that cities may need to target ameliorative measures targeting these segments of the population. By the same token, mitigation measures may need to be designed to both reach particular social groups but also to ensure that the most vulnerable are not adversely impacted by, for instance, an increase in energy prices from shifts to more sustainable energy sources (Adger and Kelly, 1999). A similar message applies to investments in local infrastructure, business assets, and market operations; making these investments also requires considering the extent to which workers may be positively or negatively affected (Viguie and Hallegatte, 2012).

2.3 Climate and Economic Dimensions

A third set of relationships involve the climate and the economic dimensions of sustainable development. There has been no shortage of studies to underline the financial risks of failing to invest in resilient infrastructure and systems. In recent years, the magnitude of the impacts of heavy storms and flooding have cast possible losses from failing to respond to climate change into sharp relief. Infrastructure, understood as city's built environment, are crucial elements in planning climate adaptation mechanisms. They include a wide array of elements, ranging from buildings, to the power grid, from industrial production facilities to water or wastewater systems to name but a few. They are especially vulnerable to its effects—as could be seen in New Orleans after Hurricane Katrina in New Orleans or Hurricane Sandy in New York—but they will be of uttermost importance for defending against some of its associated hazards—such as flooding, hurricanes, or other natural disasters.

Even as evidence of economic losses have become clearer, there have also been signs that cities can capture economic gains from investing in climate mitigation and low carbon infrastructure. For example, some cities have allocated resources for solar powered lighting or electric-powered public transport. Such investment can lead to reductions in energy bills, and free up resources to invest in other funding priorities. More broadly, among the different infrastructure, energy and waste management have the greater potential to contribute towards climate change mitigation. There is also evidence to suggest that cities need not reserve public funds for these kinds of investment; by introducing green fiscal policies, cities can encourage private capital to flow into areas that would be good for business and fiscal health. A related benefit would be potential increases in domestic and foreign investment as well as increased competitiveness.

3. Factors Influencing Integration: Multilevel Governance, Social Inclusion, Vested Interests

While there are numerous possible linkages between and other dimensions of sustainable development in cities, there is no guarantee that cities will reflect these in their climate change plans. For just as there are many possible relationships across climate and other priorities, there are also several reasons these will not be considered during planning processes. The next section highlights some of the potential barriers to integration—as well as the possible enabling reforms that could help overcome key challenges.

3.1 Multilevel Governance

Work on multi-level governance originated from the realisation that, while national governments found it difficult to make headway on global climate negotiations, cities and subnational governments were comparatively more adept in advancing climate-smart and resilient solutions. Further, many of these solutions made connections between climate and other objectives. Though this work rightly drew attention to the leading role of cities in global mitigation and adaptation efforts, it also noted that many cities enjoyed the most success in forging linkages when there was vertical interaction between national governments and sub-national initiatives (Bulkeley and Newell, 2015; Gordon & Johnson 2017; Shreurs 2008). The alignment between national and sub-national plans, according to some reviews, could help achieve policy coherence and narrow policy gaps (Corfee-Morlot et al 2009). It also had the potential to establish links between long-term visions and near-term visions; transfer technical capacity down to sub-national governments; and bring financing for subnational initiatives (Andonova et al 2009; Aylett 2015; Ryan 2014).

Recent studies have nonetheless underlined that strong vertical integration may not be needed in all contexts. For example, out of the 300 surveyed EU cities that have established their action plans, around half did not do so due to requirements from national government (Reclen, Heidrich, Salvia & Peietrapertos, 2018). Furthermore, in the case of the State of California (and many cities in California), it was the lack of federal initiatives that spurred innovative climate-smart solutions at the state or city level. In fact, in certain cases, rather than working with higher levels of government to integrate climate and other development goals-- cities such as Durban filled capacity gaps by working with transnational climate networks (e.g. ICLEI) to better access to best practices for addressing climate change (Hsu et al 2017; Acuto 2003). Yet another set of more nuanced claims has suggested that some “leading” cities with relatively strong capacities may not need support from higher levels of government but follower or

laggard cities with greater constraints may require support from above (in the case of vertical ties) or across administrative boundaries (in the case of transnational networks).

Another set of factors that could facilitate integration between climate and other goals involve the horizontal dimension of integration. Greater integration between key sectors has been underlined as critical to making the environment for more visible in planning (Nilsson and Persson, 2003). Yet, interagency coordination or horizontal linkages inside governments (and even further outward to other social sectors) have proven difficult to realise in practice. Some of the reasons main problems are 1) redundancy wherein two sectors or agencies perform the same task; 2) incoherence wherein the agendas of two different sectors have conflict with each other; and 3) lacunae wherein no relevant agency is filling a particular policy gap. Some have maintained that the best way to overcome the three mentioned challenges is to establish an overall planning authority to coordinate efforts between different sectors and to supervise the integration between different policy objectives (Lafferty and Hovden, 2003). These claims idea have been carried forward in above discussions of the vertical dimensions with some arguments contending that it is important to have both strong vertical and horizontal ties for a whole of government approach to climate and sustainable development.

3.2 Social Inclusion, Engagement, and Empowerment

Another set of factors that could play a role in frustrating or facilitating linkages between climate and especially social concerns involve mechanisms and institutions that enable engagement and inclusion of diverse voices from below. Some work has noted that the offering these opportunities can help address some of the negative distributional consequences that will inevitably result from climate change. The converse claims have been made as well: that is, inclusion can help to ensure urban residents are afforded critical economic opportunities in climate mitigation and adaptation, leading to safer and more prosperous cities (Gouldson et al, 2012). In both cases, mechanisms that encourage community participation and engagement can help ensure that a climate plan is environmentally and socially sustainable.

A related line of argument has sought to specify what kinds of participation can lead to stronger links between climate and social goals. On this point, some have sought to differentiate between a potentially symbolic consultation to a legitimate “process through which stakeholders influence and share control over development initiatives and the resources which affect them” (Rietbergen-McCracken, 1998). To underscore the difference between nominal and meaningful participation some have put forward that public participation can range from *informing, consulting, involving, collaborating, or empowering* the public, with different categories affording progressively greater degrees of influence over how decisions are negotiated and implemented (IAP2, 2014). While many studies tend to view participation and engagement positively (often with strong

normative undertones), it is not one-size-fits all. Aligning climate interventions with poverty alleviation and empowerment goals requires that participatory methods are tailored to local contexts. Particularly if efforts are made to establish links between climate and social objectives from the outside, it is imperative to ensure key stakeholders, objectives and outcome expectations are well defined in advance so they remain responsive to public concerns but align with longer term development priorities (Spash, 2001).

3.3 Vested Interests and Institutional Lock-In

A third category of factors that may do more to impede than facilitate integration between climate and other development goals are vested interests. A significant body of literature suggests that vested interests such as companies that generate or depend on energy from fossil fuels can restrain the growth of new industries such as renewables (Moe, 2013). Though these interests do not operate solely at the local level, they can sharply constrain the ability of subnational governments to pursue initiatives that align climate with deeper development priorities. For example, even though Japan has succeeded in introducing a feed-in-tariff, oligopolistic thermal companies refused access to independent renewable energy producers to existing grids (these objections were leveled chiefly on technical grounds as energy companies argued that a lack of space in their grid is reserved for nuclear based electricity).

Part of the challenge with vested interests is the work to lock-in existing infrastructures and institutions, thereby making it exceedingly difficult to introduce the policy and technical reforms that would bring together climate and development objectives. These interests can also employ nefarious means such as organised campaign of misinformation around climate change to ensure there is not a disruptive change in prevailing development patterns (Readfearn, 2018). There is nonetheless some hope that the influence of these interests can be attenuated. For example, there has been relatively more progress in advancing low carbon energy efficiency than solar and wind plans because energy efficiency requires the least amount of structural change and subject to the least amount of lock-in (Moe, 2013). Further, not all countries are equally hamstrung by vested interests; many countries in Europe have succeeded in moving forward development friendly low carbon plans despite more muted resistance than, for example, Japan.

A final point related to vested interests pertains to developing countries and small and medium enterprises (SMEs). In these two cases in particular, it will be important to include industrial interests in discussions of how to transition to sustainable low carbon business model. Some have indeed reflected on the potential to advance green industrial policies that not only invite in new businesses that can take advantage of

climate imperatives, but to help existing enterprises keep up with changes in the economy.

3.4 Other Factors

The factors that may impede or facilitate integration between climate and other development goals in cities is not exhaustive. In fact, the listed sets of considerations may not be the only (or even the primary) challenge that cities face in integrating sustainability into their climate plans. Other factors—such as a lack of finance or shortages of administrative capacity—may also play a role in limiting this integration (Rock, 2002). At the same time, there is a fast growing literature on sustainability transitions that underlines how niche innovations interact with broader markets, policies and institutions that interact with even wider ranging norms and economic conditions (Geels, 2002). These larger theories may nonetheless prove challenging to translate to the next part of the paper: an initial review of climate and related plans in select cities in Japan.

4. Reviewing Climate Plans in Japan

This section of the paper involves a preliminary review of the climate change plans of two cities in Japan: the large and well-known city of Kyoto; and the smaller and less recognized city of Matsumoto. The reviews look at whether and to what extent the linkages between climate and the environmental, social, and economic dimensions of sustainable development are evident in climate and other relevant plans. It also examines if there is any evidence of the factors in section of the paper that facilitated or prevented integration across these issues. It merits underlining that the review is based exclusively on desk study. As such, any inferences drawn from the review remain tentative and subject to further analysis based on interviews with relevant staff in the respective cities. Further, the approach employed in this section, will be replicated for other cities in Japan so as to expand the evidence base and ground even preliminary findings in a deeper body of knowledge. Last but not least, as also underlined in the literature review, Kyoto and Matsumoto are very different cities in terms of their population, geography, economic structure, and positioning in the Japanese government. These differences may contribute to any differences identified in the degree of integration between climate and other sustainability objectives as well as the reasons for those differences.

4.1 The Case of Kyoto

4.1.1 City and Climate Plan Background

As the international birthplace of the Kyoto Protocol, the city of Kyoto is widely recognised as an agenda setter on climate and environmental policies. Located in the western centre of Japan and occupying roughly 4,600 km², Kyoto is a thriving metropolis of 1.47 million people. An historical city, by turns both traditional and modern, Kyoto's main industries include tourism, research, manufacturing and services; its estimated GDP per capita was US 41,410 in 2015. Kyoto carries designated city status, meaning that it has been granted administrative functions typically reserved for Japanese Prefectural Governments.

In 1997, Kyoto was of the first cities in the world to announce its planned adoption of global warming countermeasures. Subsequently, in 2004, the city officially enacted a directive outlining its efforts to address climate change. This led to the formulation of Kyoto's climate action plan in 2006, which has since been modified several times to ratchet up emissions reduction targets in line with national and international commitments. The current plan—last revised in 2017—pledges to reduce 1.335 million tons of greenhouse gases (GHGs) by 2020, reaching zero carbon by the latter half of the 21st century through a combination of 98 actions, 36 policies, and 19 directions, all comprised under Kyoto's six visions for a low carbon society. The six visions include a focus on transit and mobility, forest restoration, energy and recycling, environmentally friendly lifestyles, green economic activities, and waste reduction, respectively.

Accordingly, Kyoto's action plan sets out emissions reduction priorities for the immediate (present-2020), medium (2030-2040), and long-term (2050 and beyond). Thirteen mitigation strategies have been proposed, clustered under the following sectors and activities: residential, commercial, industrial, transport, waste, addressing GHGs excluding carbon dioxide, and other reduction actions, all defined by a suite of supply and demand-side policy measures. The action plan also features a section on climate change adaptation, highlighting actions to build resilience against natural disasters, protect health and safety, and minimise impacts on aquatic resources and ecosystems.

4.1.2 Integration between Climate and Other Dimensions of Sustainable Development

Kyoto's action plan puts forward a number of policy measures focused on environmental conservation, resource management, and pollution prevention. Nature-based urban planning solutions are referenced throughout the plan, such as expanding the amount of green spaces, utilising biomass for heating, and introducing porous

pavement to improve water quality and drainage. Other proposals include constructing sustainable buildings, increasing energy efficiency and the use of renewables, encouraging pedestrian access by widening public transportation options and the availability of eco-vehicles, and enhancing waste reduction efforts.

Another key facet of Kyoto's climate action plan is an emphasis on citizen engagement. Local residents are identified as having an important role to play in carrying out the plan's stated goals and objectives, which is clearly reflected in several policy proposals. For instance, the plan discusses making use of information and education campaigns, community partnerships and incentives for the promotion of more eco-friendly lifestyles. On the other hand, little mention is given to issues of social inclusion and equity: whereas compact land use planning is highlighted as one solution to addressing the needs of the elderly, for example, the plan does not indicate how similar interventions might be tailored to other vulnerable individuals, such as persons with disabilities.

The plan also presents a range of strategies and measures aimed at mobilising the private sector to take action on climate change. In addition to proposing carbon offsetting, renewable energy mandates and the introduction of CO₂ reduction plans for business, the plan highlights the need for public-private-partnerships to incubate low-carbon technologies and initiatives. Green procurement is also listed as a means towards this end.

Vertical and horizontal cooperation are important considerations taken up by Kyoto's climate action plan. Kyoto maintains strong ties with the national government since being inducted in Japan's "Eco-Model City" program in 2013: and to this day utilises the platform to leverage funding and engage with other local authorities on climate issues. The city also participates in international networks on climate change including as a member of ICLEI and the Covenant of Mayors. Further, Kyoto also maintains sister city status with Paris.

4.2 The Case of Matsumoto

4.2.1 City and Climate Plan Background

Matsumoto is the second most populous city of Nagano Prefecture, Japan. An old castle town located at the heart of the Japanese Alps, Matsumoto has a population of 243,293 inhabitants (2015), being one of the few municipalities whose population is growing within Nagano Prefecture. It is a regional commercial centre and was designated as a special city in 2000. Its economy is predominantly based on tertiary activities—including retail and tourism—but has a significant share of secondary

industries, especially electronics. Matsumoto also has a strong presence of dairy producers and manufacturers.

Two different plans have been reviewed for this paper. First, the “Third Basic Environment Plan of Matsumoto City”, and second, the “Matsumoto City Global Warming Action Plan”. The “Third Matsumoto Environmental Basic Plan” is the higher order plan coordinating other sectoral plans such as plans focusing on greenery or decarbonisation. Its current edition was launched in 2016, and reviewed the original plan from 2011. The plan is the basic framework imagining the future of Matsumoto—a more sustainable and healthy city where everybody can enjoy and live in harmony with nature, in which people recycle and work together to improve the environment. The plan has 6 sections: 1. Basic matters; 2. Summary of the city; 3. Environmental status; 4. Aim of the plan; 5. Development of measures; 6. Management of the plan’s progress. The Third Basic Environment Plan was launched to promote more systematic and comprehensive environmental actions, paying special attention to the municipal context. To do so, it establishes five main pillars: 1. A town that considers the global environment as irreplaceable; 2. A town that reduces environmental impacts and where resources circulate; 3. A town where to live safely and with ease of mind; 4. A town that appreciates the blessings of nature? (自然の恵みを大切に受けつぐまち); 5. A Town that brings up greenery, water, and history (p. 53). The five pillars create multiple linkages with other environmental, social, or economic elements.

Under the city’s Third Basic Environment Plan is the “Matsumoto Global Warming Action Plan”; its current version was issued in 2016 also reviewing the 2011 edition. The plan is 75 pages long and is structured in 6 main sections: 1. Purpose of the plan; 2. Summary of the city; 3. Current GHG emissions; 4. Reduction targets; 5. Efforts to reduce GHG emissions; 6. System to promote the plan. It is formulated based on the “Global Warming Prevention Act”, which obliges municipalities to prepare their own climate change adaptation plan according to their natural and social conditions. The current plan emphasises on setting goals for GHG reduction targets while working with related plans to achieve its overall goals and remaining sustainability-related objectives (p. 12).

4.2.2 Integration between Climate and Other Dimensions of Sustainable Development

The Third Basic Environment Plan—especially in its first, second, third, and fourth pillars—establishes linkages with other environmental goals. The first pillar looks beyond Matsumoto by acknowledging the universal nature of sustainable development and the need to act locally to fight against global warming; it puts forward the idea of transitioning to a low-carbon society. At its core, the second pillar, lays the idea of

minimising impacts upon the environment. It delves into resource circulation and waste management, including measures to protect farmland and forests, which are progressively being abandoned because of population ageing. The third pillar considers pollution. For instance, it seeks to preserve the richness of Matsumoto's nature and to maintain blue skies—in relation to low air pollution—a green city, and clean water. The fourth pillar addresses the connections between biodiversity and population decline in small and depopulating villages.

Social concerns come to the forefront especially in relation to issues consequential to a hyper-ageing society; this is one of its three main guiding principles of the Third Basic Environment Plan. It stresses the need to build a city where humans can live in harmony with nature, developing their activities with little impact on the environment (p. 52). Unsurprisingly, this all-encompassing goal includes multiple linkages such as the preservation of the city's environment, build a sustainable society that has a low impact on the environment, and efforts to protect the global environment. Depopulation is linked also to natural ecosystems and biodiversity, since the depopulation and abandonment of small villages in mountainous areas will endanger them by means of mismanagement of natural assets.

Economic aspects seems by-products of other goals or a needed part of measures for their implementation. The plan, however, says that there will be resources available for businesses working towards a green shift (p. 100). The promotion of material circulation, in line with the national government's emphasis on the 3R, has clear economic linkages since it transforms the productive model of the city. The plan also hints at reducing the city's automobile dependency and fostering other transportation means. In terms of infrastructure, the plan fosters the change to renewable energy sources and the introduction of energy-service company (ESCO) projects not only in public facilities but also among the private sector.

Throughout the plan there are few references to vertical and horizontal integration. Regarding vertical integration between different levels of government, the introduction summarises the different national and regional plans upon which Matsumoto's own is built. Then, it highlights that the third basic environment plan of Matsumoto will work as the higher level of reference for any other municipal plan dealing with the environment—such as the city's global warming action plan, which focuses on decarbonisation strategies. The references are somewhat vague, just mentioning “collaboration with this agency” or “in accordance to this regional/national plan”.

Mention of stakeholder engagement is also unclear. The plan merely notes the need of companies, schools, citizens, the local administration, to combine efforts to fight against climate change (p. 60). A recurrent trope throughout is the necessity of voluntary

cooperation from private agents, without further specification. Furthermore, public awareness raising education activities also emphasise the importance of preserving the natural environment.

5. Preliminary Conclusions and Way Forward

Overall, the paper suggests that there is a compelling case to integrate SDGs into climate plans in cities. Some of the advantages from this integration include saving resources, attracting new investments, and addressing growing emerging social concerns. The paper further highlights that these interrelationships are not always positive; there can be synergies as well as trade-offs. Cities will need to become increasingly adept at capitalizing on these synergies and managing these trade-offs. Some of the more likely areas where this promises to be important include the interplay between climate and water, waste and air pollution; employment and social inclusion; and investing in low-carbon, resilient infrastructure.

The paper also points to several possible factors that could facilitate or impede integration of climate and sustainability concerns. The relevant literature notes that these could include, *inter alia*, multilevel governance, participatory engagement mechanisms, and vested interests. There are also more conventional concerns over administrative capacity and larger systems level theories that could also help explain why integration does or does not happen.

There is nonetheless a need to determine whether cities are indeed making the links between climate and SDGs; and whether the proposed sets of factors are promoting or preventing those linkages. The paper suggests that Kyoto and Matsumoto city are indeed making the linkages while gaps may exist in other areas (especially involving the social dimensions of sustainable development). The analytical framework in the appendix can be used to assess the situation across a wider range of cities and evaluate potential areas for further integrating sustainability concerns into climate plans.

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Appendix: Analytical Framework

City Names	Kyoto	Nagano	(Yonago)	(Matsuyama)	(Yubari)	(Morioka)
Climate x environmental dimensions						
climate x water x food policy integration						
Climate x air pollution policy integration		✓✓				
Climate x water policy integration	✓✓	✓✓				
climate x green space policy integration	✓✓	✓✓				
energy x transport policy integration	✓✓	✓✓				
energy x urban forests policy integration	✓✓	✓✓				
energy x health policy integration						
energy x waste management policy integration	✓✓	✓✓				

Climate x social dimensions						
climate x creation of green industries	✓✓	✓✓				
climate x creation of green jobs		✓✓				
climate x address depopulation		✓✓				
climate x address vulnerable citizens	✓✓					
Climate x economic dimensions						
climate x leads to transitions in infrastructure	✓✓	✓✓				
climate x leads to transitions in energy systems	✓✓	✓✓				
climate x leads to transitions in waste management	✓✓	✓✓				
climate x leads to green fiscal policies	✓✓					

Multilevel governance						
Aligns national and subnational policies	✓✓	✓				
Participates in transnational networks	✓✓					
Promote interagency coordination		✓				
Overall planning authority resides over climate change						
Social inclusion						
Aligns with poverty alleviation						
Process of informing, consulting, involving, collaborating, or empowering stakeholders						
Encourages community participation/engagement	✓✓	✓				
Vested interests						

Facing infrastructure lock-in						
Facing institutional lock-in						
Other factors						
Facing financial limitation						
Facing administrative limitation						
Sustainability transitions						
System level changes						

Analysing climate action plans of selected UK cities for their SDG alignment

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Abstract: In UK, the Climate change Act of 2008 has placed a binding target of reducing the net carbon emission in 2050 by at least 80% compared to the 1990 baseline. With a high share of urban population, the contribution of cities and urban areas towards climate change mitigation and adaptation becomes crucial. UK being a signatory to the Sustainable Development Goals (SDG) in 2016, there is a new emphasis on the sustainability of cities as well. In this paper, a preliminary analysis of climate action initiatives of three UK cities (Bristol, Leicester and Milton Keynes) and their alignment with the SDG is presented. We used a text mining approach to analyse the climate action plans and then use this to map the alignment with the SDGs. We find that climate action plans have not focused on the sustainable development goals or the SDGs and their focus remains limited mainly to mitigation activities through promotion of renewable energies at homes and in buildings and actions on transport. However, climate action plans could influence a significant number of SDGs and an integrated approach could be beneficial for the cities and their residents.

Keywords: climate action, SDGs, UK cities,

1.0 Introduction

According to the UN (2018), only 751 million people (or 30% of the population) lived in urban areas in 1950 but in 2018, 55% of the global population (or 4.2 billion people) live in urban areas. This represents a significant growth in urbanisation and the report suggests that by 2050, another 2.5 billion people will be added to the urban population, taking the share of urban population to 68% globally.

Urban areas now account for 80% of the global GDP (World Bank, 2018) and urban economic activities, particularly industries and services, create opportunities for income generation and livelihoods. However, urban areas tend to be more resource intensive to support higher levels of economic activities and better lifestyle and accordingly, they contribute to environmental degradation and climate change. Simultaneously, cities are very vulnerable to natural calamities and service disruption that can arise because of global warming. The highly concentrated nature of population, infrastructure and facilities increases the exposure to risk and potential for adverse effects.

Facing these challenges, many cities have developed action plans to mitigate climate change effects and adapt to the changed conditions. While this is a step in the right direction, it appears that the city climate action plans tend to be narrowly focused and misses the opportunity to take a more integrated approach. Cities critically rely on interrelated complex systems involving five essential building blocks (see Fig. 1): efficient local government management, effective local service provision, ensuring wellbeing of urban dwellers, promoting economic activities in the city, and ensuring a safe and sustainable environment. Each of these areas could contribute to climate action but the attention is often limited to energy and transport-related activities. This limited scope and a disjointed approach does not appear to align well with the idea of sustainable development, particularly in the urban contexts. Yet, the UN Framework Convention on Climate Change (UN, 1992) clearly articulated the idea of sustainable development in the context of climate change. More recently, the Sustainable Development Goals (SDGs) offer an opportunity to appreciate the whole system perspective of local level aspirations, actions and outcomes. This can be used to identify potential for inter-connections and explore the areas of weaknesses and impediments that influence the outcomes at the city level. This also offers an opportunity to create awareness of SDGs at the governance level as well as at the level of other stakeholders (users, service providers, regulators, financial institutions, innovators, etc.), which is essential for generating wider acceptance of SDG objectives and co-creation of a pathway for realising the SDGs.

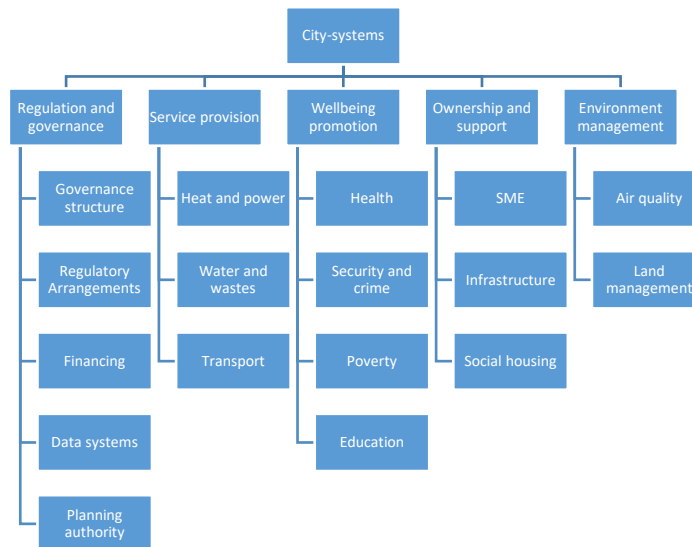


Fig. 1: Graphic presentation of city systems (based on World Bank (2010)).

It also appears that the decision-making in cities favours near-term interventions over strategic long-term visions and the implementation of any plan is greatly influenced by the prevailing conditions in a given city. Depending on the nature of a city (industrial, post-industrial), demographic change (e.g. increasing populations, aging populations, changing social structures), economic condition (growth, recession, economic transition) and social challenges (inequality, poverty, law and order issues, etc.), among others, the implementation of any plan can be affected. Further, given the changes are fast-paced and because cities operate within finite resources (economic, financial, human, natural and social), the trade-off between current and future can affect the preparedness of cities and this influences their SDG readiness significantly.

The case is not very different in the UK. Various urban administrations have adopted plans to mitigate climate change and adapt to the warmer climate and take precautionary measures to manage the consequent risks. Heidrich et al. (2013) have investigated the climate preparedness of 30 UK urban areas and found that while all areas acknowledge the climate change threat, there is significant variation across them in terms of preparedness. Similarly, Heidrich et al. (2016) and Reckien et al. (2018) investigated the climate policies and plans of European cities and find significant variations in terms of plans and actions across cities to deal with the threat of climate change. However, these studies did not focus on the linkage with sustainable development and the SDGs.

This paper presents a preliminary analysis of the integration of the SDGs in the climate action plans of urban areas in the UK. The main objective is to identify whether city-level climate actions have considered sustainable development of cities and whether they have aligned their actions and plans with the SDGs. The paper is organised as follows: the following section presents an overview of local authorities in the UK, maps their roles and responsibilities and highlights the policy context for their climate actions. Section 3 focuses on the methodology and materials used in the

paper. Section 4 presents the main findings and finally section 5 offers some concluding remarks and recommendations.

2.0 Local authority background in the UK

The term ‘local government’ or ‘local authority’ is variously used in the UK. Sandford (2019) indicates two broad categories: principal authorities (comprising of county, district and unitary authorities) and local councils (also known as parish and town councils and represent a tier of government closest to the electorate). The principal authorities serve urban and rural areas but their organisation varies across different countries within the UK: for example, in Scotland, Wales and Northern Ireland, principal authorities are single tier only whereas England has single-tier and two-tier principal authorities. In terms of numbers, there are 418 principal authorities in the UK, with a majority of them (353) in England and the rest in Wales (22), Scotland (32) and Northern Ireland (11).

According to the Committee on Climate Change (2012), different categories of local authorities in the UK provide different services in urban and rural areas. In England, out of 353 local authorities in total (NAO, 2017), there are 125 single-tier authorities serving cities, urban areas and larger towns. They serve 16% of the geographical area of the country representing 53% of the population. These include 33 London borough councils, 36 metropolitan borough councils and 56 unitary councils. In addition, there are 27 county councils in two-tier areas, serving rural areas representing 84% of the area and 47% of the population. There are 201 district councils within the county council areas providing a sub-set of services (e.g. housing, planning permission, etc.). Further, there are 79 single purpose local authorities providing a specific service (such as police, public transport, waste collection, etc.). These local authorities in England are responsible for social care, transport planning, highways, public health, environment, waste collection housing, planning, local tax and leisure (NAO, 2017). Table 1 presents the distribution of English local authorities and their roles.

Moreover, a few authorities have created combined authorities (such as Greater Manchester Authority) and more combined authorities may emerge in the future. These combined authorities have responsibility over transport, economic growth, employment and business support, housing, planning and land disposal, and further education and skills (NAO, 2017).

Table 1: Roles and functions of local authorities in England

Function	Metropolitan		Shire areas		London councils
	Borough Councils	Unitaries	County councils	District councils	
Education	X	X	X		X
Highways	X	X	X		X
Transport planning	X	X	X		X
Passenger transport		X	X		
Social care	X	X	X		X

Housing	X	X		X	X
Libraries	X	X	X		X
Leisure and recreation	X	X		X	X
Environmental health	X	X		X	X
Waste collection	X	X		X	X
Waste disposal	X	X	X		X
Planning application	X	X		X	X
Strategic planning	X	X	X		X
Local taxation	X	X		X	X

Source: Adapted from Climate Change Committee (2012).

2.1 Legal and policy context for climate action by local authorities

A number of legislations in England influence local authorities in their climate change mitigation and adaptation activities (TCPA and RTPI, 2018). Section 19 of the 2004 Planning and Compulsory Purchase Act, as amended by Section 182 of the Planning Act 2008¹ states: ‘Development plan documents must (taken as a whole) include policies designed to secure that the development and use of land in the local planning authority’s area contribute to the mitigation of, and adaptation to, climate change.’ In addition, the National Planning Policy Framework 2019 (Ministry of Housing, Communities and Local Government, 2019) places sustainable development at the heart of planning. It requires that the plans and decisions about development ‘apply a presumption in favour of sustainable development’. The Framework requires local authorities to take a long-term perspective (at least 15 years) by developing strategic policies for the development and use of land in their area. The strategic policies have to make adequate provision for housing needs, provision of infrastructure and services (such as transport, water, energy, waste management, and flood risk and coastal change management, among others), community facilities and protection of the nature and the environment. The framework specifically requires plans to take ‘a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures’. The earlier framework (of 2012) also focused on sustainable development and climate change but the new framework better integrates these agendas and requires local authorities to consider an integrated perspective in their land use and planning decision-making process.

In addition, Section 1 of the Climate Change Act 2008 requires the net carbon emissions in the UK in 2050 to be at least 80% lower than the 1990 baseline. Section 61 of the Act empowers the Secretary of State to issue guidance regarding assessing the present and future impacts of climate change in relation to authorities functions and developing policies and plans for mitigation and adaptation. Section 62 of the Act imposes reporting requirements on the local authorities relating to climate change mitigation and adaptation. The Act refers to sustainable development in relation to

¹ available at <https://www.legislation.gov.uk/ukpga/2008/29/section/182>

policies and proposals to meet the emission reduction targets (Section 13), adaptation to climate change (Section 58), and renewable transport fuel obligations (Schedule 7). However, there is no allocation of the carbon budget at the city level and outside the reporting requirement, the Act does not directly impose any obligations on the local authorities.

The Planning and Energy Act 2008² empowers local authorities to require a new development to source a proportion of its energy from local resources. This also allowed the local authorities to set higher energy efficiency standards for new buildings, although the powers related to energy efficiency were repealed in 2015.

Moreover, the Covenant of Mayors, launched in 2008, promoted voluntary actions at the local government level. This is a grouping of local governments in Europe with the objective of exceeding the European targets on climate change and energy on a voluntary basis. The signatories commit to developing a Sustainable Energy and Carbon Action Plan to take practical actions to mitigate climate change and to adapt to it. The signatories also undertake to report progress every two years. Many UK cities are signatories to this group. 47 urban councils in the UK are signatories to this Covenant, of which 10 are from Scotland, 2 from Wales, one from Northern Ireland and rest 34 from England³.

The policy context is complex but the recent emphasis of the policy framework is to pay attention to climate change and sustainable development.

3.0 Materials and methodology

In order to develop the big picture regarding climate action plans of UK cities and their alignment with the SDGs, we have started with a macro-level perspective. Based on the list of signatories to the Covenant of Mayors from the UK, we considered a selection of 26 local authorities from different geographical location of the country. This selection was informed by availability of information about the urban area, its population (e.g. small sized cities were excluded), and resource constraints. Some basic information about these cities was then collected to develop an initial scope of the cities. This also involved a quick scan of council websites to find any relevant information about climate mitigation, adaptation and sustainable development plans. This indicated that all 26 cities have climate mitigation plans. Most of them also have an adaptation plan but very few have a separate plan for sustainable development goals. Bristol has articulated its thoughts about the SDGs while cities like Oxford, London, Glasgow and Milton Keynes have also taken steps to work towards these goals. However, at this stage, the alignment of the climate action plans with the SDGs was not considered.

In order to investigate the city climate action plans in a systematic way, we relied on text analysis using software. Although a range of software options is available, we have used NVivo and Voyant Tools (an online package) for a quick analysis of some texts. The statistical analysis of words in each document and the graphical representation either in word clouds or word trees generated a better idea of how

² http://www.legislation.gov.uk/ukpga/2008/21/pdfs/ukpga_20080021_en.pdf

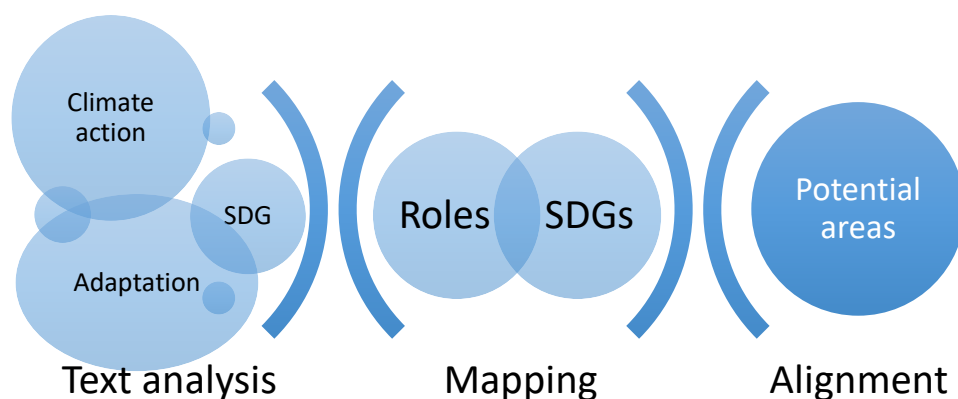
³ <https://www.covenantofmayors.eu/about/covenant-community/signatories.html>

different themes are associated in the documents. The text analysis was done for Bristol, Leicester and Milton Keynes.

Parallel to the document / text analysis, a mapping of local authority services and the related SDGs was attempted. This allowed us to identify the SDGs that could be targeted at the city level and which of them could have a link with the climate change theme. This mapping exercise was then compared with the results of the document analysis to explore to what extent cities are directly or indirectly influencing the climate-driven SDGs.

This is a work in progress and we are only reporting a preliminary analysis here but it produces interesting results, a more detailed analysis would be considered for a wider range of cities in the UK.

Figure 2: Work flow diagram



4.0 Analysis and discussion

We first present the results of our text analysis and then the mapping of local authority roles and the SDGs will be presented. Finally, we discuss the alignment of climate actions of UK cities with the SDGs.

4.1 Text and document analysis

As the Climate Change 2008 is a relevant legislation for climate change mitigation and adaptation, we started with this document. In this document of 38,890 words, 'climate change' appears 323 times, but 'sustainable development' appears 4 times although the word 'sustainable' appears 17 times in the text. The word cloud of the commonly occurring terms in the act is shown in Fig. 3. It is interesting to note that

words	City (274) Bristol (270) Emissions (192) Carbon (154) Climate (113) Targets (102) Framework (100) Transport (99) Industrial (90)	City (56) Energy (52) Carbon (29) Programme (29) Change (27) New (26) People (23) Reduce (23) Climate (22)	Carbon (43) Plan (35) Low (30) Action (29) Milton (22) Keynes (21) Existing (19) Transport (18) Strategy (17)
Most common collocated words	1) Bristol-city – energy – council; 2) Energy – security – Bristol – climate – city – framework – efficiency; 3) Climate – change – security – framework – energy -	1) climate –change – programme – action 2) Leicester – getting – city – healthy – active – communities 3) energy – efficient – use – project	1) low – carbon – action – plan; 2) carbon – plan – action – emission – living; 3) energy – efficiency – schemes – develop – use - transport
Occurrence of key terms (frequency)			
Sustainable	31	16	8
Development	28	8	3
Sustainable development	2	1	0
Mitigation	4	0	0
Adaptation	4	0	0

The word linkages shown in figures 4 -6 bring out the distinctive focus of each plan. For example, energy-related carbon emission reduction in Bristol comes out quite clearly. Ensuring energy security is given a strategic focus, where the cost of service appears as a driver. In the case of Leicester and Milton Keynes, on the other hand, the focus on the community and businesses becomes clear. The emphasis on developing plans for businesses and the community distinguishes Milton Keynes’ plan from that of Leicester’s but by including homes, people (including children and youth) and their health, Leicester’s plan appears to have a wider scope compared to the others.

Our test with climate plans of three UK cities shows that a systematic analysis of text documents using available software can be a suitable approach undertaking a quick and macro-level analysis. This can highlight possible themes for further analysis and can be easily used to develop a comparative picture.

Fig. 4: Word linkage for the Bristol city climate action plan

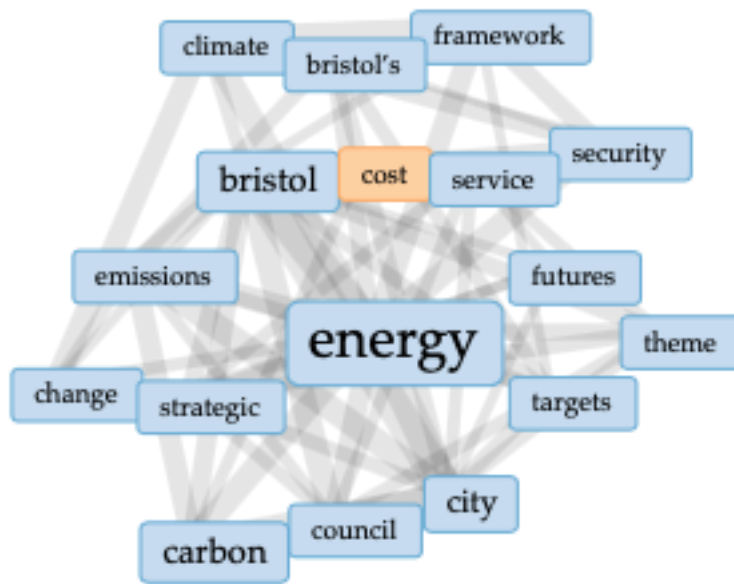


Fig. 5: Word links for the Leicester Low carbon city plan 2014

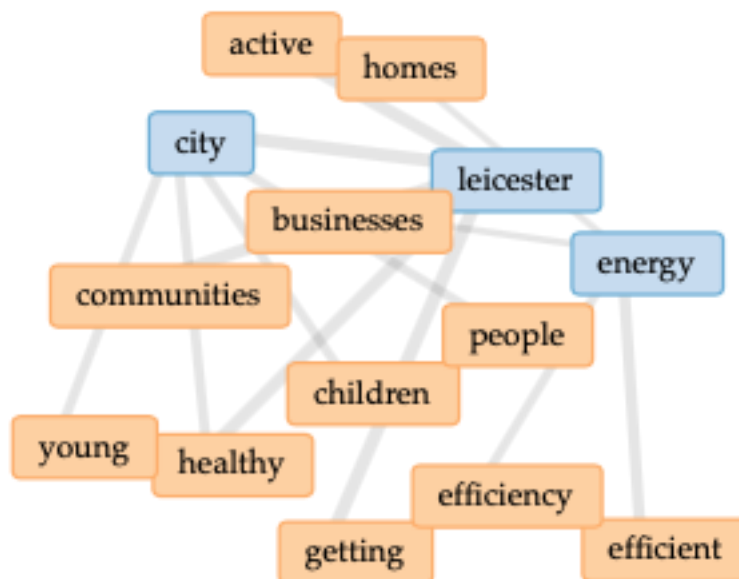
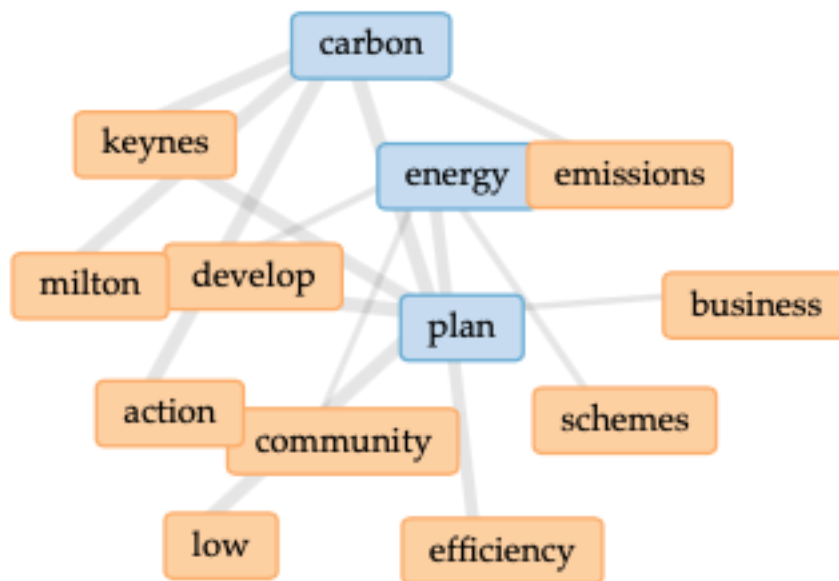


Fig. 6: Word links for Milton Keynes low carbon plan 2012



4.2 SDG mapping of climate actions

The Sustainable Development Goals launched in 2015 by the United Nations are global goals to be reached by 2030. A number of goals are relevant at the city level, with goal 11 directly relevant for cities (aiming at sustainable cities and communities). The goal 13 (climate action) is particularly relevant for the climate challenge but several other goals (such as poverty, hunger, water access, energy access and efficiency, education, health and wellbeing, production and consumption, etc.) are all relevant at the city level.

Nilsson et al. (2016) proposed a mapping framework to identify the interaction of one SDG with the rest. They suggest a seven-point scoring scale to distinguish the interactions that can positively influence from those that can hinder the progress. They suggest that the mapping should start from one SDG and consider its interaction with the remaining 16 to identify the possible trade-offs. Nerini et al. (2018) have mapped the energy-related SDGs across other SDGs. The evaluation relied on evidence from available literature and interactions with experts. However, a detailed mapping exercise using the above approach is a demanding task and within the limited time and resources, this could not be adopted here. This could be an area of future work.

A simpler approach is used below which considers an example of possible city level SDG targets and which of these are influenced by climate actions positively or negatively. Table 3 presents the details. The city level SDG example is adapted from Bristol (Bristol Green Capital Partnership, 2018). This table indicates that goal 7 is inextricably related to SDG 13 while climate action reinforces several other SDGs (namely 1, 3, 6, 9, 12 and 15). For majority of the remaining ones, climate action has

an enabling effect while climate action may have a constraining effect on goal 10 (inequality among countries) and may not have any important role in goal 16 (peaceful and inclusive societies). This suggests that climate action at the city level has the potential to influence a range of SDGs but this requires a careful integration of the SDG agenda.

The current action plans are more concerned with mitigation of carbon emission through promotion of renewable energies at homes and in buildings as well as through action on the transport sector. The adaptation is mainly concerned with flood prevention and managing the flooding risk. A broader integrated approach could create co-benefits and achieve a better outcome at the city level.

Conclusion

This paper presented a preliminary analysis of city level climate actions in the UK to find out whether they are aligned with the SDGs. It has initially considered 26 cities, which are signatories of the Covenant of Mayors and then taken three cities, namely Bristol, Leicester and Milton Keynes to undertake a more systematic analysis. The climate action plans were analysed using text analysis software to identify the similarities and differences in them. The SDG mapping was then used to see where climate action could influence the SDGs. It is found that the Climate Change Act 2008 does not directly impose any obligation on the cities, as the act does not even mention the term 'city'. However, there is a reporting obligation of local authorities to inform their policies and progress in terms of contribution to the overall national objective of greenhouse gas emission reduction. The city level plans differ significantly but the link to sustainable development or sustainable development goals is limited, mostly indirect. Our mapping however shows that climate actions can influence achievement of a large number of city level SDGs and accordingly, a better alignment of the climate action plans could be beneficial for the local authorities and the citizens.

Further work is required to map the SDG targets against the climate action objectives. A more thematic analysis of the documents will also be useful and insightful. This is the agenda for further work.

Table 3: Mapping of SDGs on climate actions

Goal	Aim	Examples of City Goals	Effect of climate action	City level climate actions Goal 13
Goal 1	End poverty in all its forms everywhere	50% less people in poverty in the city compared to now	Reinforces the achievement of Goal 1	Climate resilience positively improves potential for poverty reduction
Goal 2	End Hunger, achieve food security and adequate nutrition for all and promote sustainable agriculture	End all forms of malnutrition, including children under 5, adolescent girls, pregnant women and older people	Enabling effect	Climate adaptation measures reduce the risk of food insecurity
Goal 3	Attain healthy life for all at all ages	Reduce by 1/3 all premature deaths from non-communicable diseases	Reinforces the goal achievement	Climate actions reduce pollution, promotes sustainable activities to support this goal
Goal 4	Provide equitable and inclusive quality education and life long learning opportunities for all	Ensure access to quality early childhood care and education and significantly increase the number of people with relevant skills for decent jobs	Enabling effect	Climate actions create new opportunities for jobs and skills
Goal 5	Attain Gender equality, empower women and girls everywhere	End all forms of discrimination against women and girls	Enabling effect	New opportunities offer potential for a non-discrimination
Goal 6	Secure water and sanitation for a sustainable world	Substantially increase efficient use of water	Reinforces the goal achievement	Climate resilience to improve awareness of efficient water use
Goal 7	Ensure access to affordable, sustainable and reliable modern energy services for all	Significantly increase renewable energy use and improve energy efficiency	Indivisible - inextricably linked	Climate action and Goal 7 go hand in hand
Goal 8	Promote strong, inclusive and sustainable economic growth and decent work for all	Decent employment for all	Enabling effect	New businesses and skills improve the opportunity for decent jobs
Goal 9	Promote sustainable industrialization	Better resource efficiency and cleaner technologies for industries	Reinforces the goal achievement	Climate action drives adoption of clean technologies
Goal 10	Reduce inequality within and among countries	Reduce exclusion in the society	Could be constraining	New technologies could increase exclusion of certain section of the population
Goal 11	Build inclusive, safe and sustainable cities and human settlements	Inclusive, safe and affordable housing and services for residents	Enabling effect	Climate action supports affordable services in cities
Goal 12	Promote sustainable consumption and production patterns	Substantially reduce waste and improve awareness of consumption	Reinforces the goal achievement	Climate actions support awareness about consumption and production
Goal 14	Attain conservation and sustainable use of marine resources and seas	Reduce marine pollution and resource use	Enabling effect	Cleaner production contributes to waste reduction and resource demand
Goal 15	Protect and restore terrestrial ecosystems and halt all biodiversity loss	Ensure conservation and sustainable use of ecosystem	Reinforces the goal achievement	Effective land management contributes to ecosystem protection
Goal 16	Achieve peaceful and inclusive societies, rule of law, effective and capable institutions	Reduce violence and related death	no direct influence	Climate action likely to reduce the risk of damage and hence social tension
Goal 17	Strengthen and enhance the means of implementation and global partnerships for sustainable development	Promote different forms of partnerships	Enabling effect	Climate action promotes different partnerships

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Papers from Session 2

Energy Access and the SDGs

Experiences from Solar PV Rural Energy Businesses in Malawi

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ABSTRACT

This paper draws out translational learning for off-grid energy access initiatives from a case study in Malawi. Deploying solar PV ‘Charging Stations’ in four rural communities, the Sustainable Off-Grid Electrification of Rural Villages (SOGERV) project set out to establish sustainable, community focussed, energy businesses. The market assessment that comprised a major stage of the project initiation is presented here. The financial performance of the SOGERV businesses is then summarised for comparison. It is found that market assessment recommendations for smaller, more affordable portable products were largely accurate. The established businesses tested this market with a range of products and analysis shows that sales are largely in line with market assessment product predictions. However, a larger market than predicted appears to exist and that there is more appetite for the larger ‘household-scale’ portable products than anticipated. Productive Use of Energy (PUE) customers were harder to establish and were limited to a small number of barber shop, cold-drink sales, video show and shop lighting customers. Stand-alone PV systems were not affordable for the majority and most PUE customers co-located with the charging infrastructure, suggesting a need to facilitate enhanced co-location opportunities or for electricity distribution infrastructure.

Keywords: Off-Grid, Solar PV, SDG7, Productive Use of Energy, Market Assessment

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1 Introduction and Background

Despite significant progress being made in the last decade, only around 35% of the 910 million people in Sub-Saharan Africa (SSA) has access to electricity (IEA, 2017). The national grid in Malawi serves 10% of the population with only 4.7% of the rural population being connected despite accounting for 83% of the population (GoM, 2018) (World Bank, 2016).

The current Malawi National Energy Policy (GoM, 2018), targets increased renewable energy deployment by 2030, including deployment of 50 ‘green’ mini-grids (GoM, 2017). However, the sector is still young and learning on sustainable models for off-grid electrification in the Malawian context are yet to be well established. Rural energy projects in Malawi typically include aspects of community ownership and operation, and target a public facility such as a primary school or health centre (Dauenhauer & Frame, 2016a) (Dauenhauer & Frame, 2016b). Despite providing high short-term social impact, many of these projects have fallen short of sustainability expectations, typical of the historical experience with off-grid renewable energy projects in sub-Saharan Africa (Martinot, et al., 2002) (Chaurey & Kandpal, 2010). However, decentralised and renewable solutions are deemed essential to achieving 2030 ‘energy for all’ targets (IEA, 2017). Supported by the dramatic decrease in technology costs in recent years, new options such as Solar PV energy kiosks and micro-grids are proving feasible for meeting lower tier electricity needs (ESMAP, 2014) (Roche & Blanchard, 2018). In addition, innovative ‘social’ business models that combine community based approaches with entrepreneurship are demonstrating improved sustainability (Chaurey, et al., 2012) (Munro, et al., 2015) (Katre, et al., 2018).

The Sustainable Off-Grid Electrification of Rural Villages (SOGERV) Project ran from 2015 – 2018. The project design was strongly influenced by an evaluation of PV project sustainability that took place in Malawi in two phases between 2015 and 2017 (Dauenhauer & Frame, 2016a) (Buckland, et al., 2017). Although all the classic sustainability factors (Ilskog & Kjellstrom, 2008) were considered, economic sustainability was a key target and is the focus of the remainder of this paper. Specifically, two contributions by the University of Strathclyde (as an academic partner in the project) are described: firstly, a market assessment undertaken during project initiation (Section 3), and secondly, collation and analysis of financial records from the businesses over the first 12-18 months of operation (Section 4). Key lessons for off-grid system deployment in Malawi and SSA are drawn out and discussed in Sections 5 & 6.

2 Methodology

The SOGERV market assessment aimed to estimate the demand for a range of renewables-based energy products in four rural locations in southern Malawi. The study implemented a custom survey at each location totalling 314 households and 46 businesses. Populations were estimated in each location through a minimum spanning tree solution and GIS data (Figure 1). The resulting maps allowed for the determination of number of households and their density in the surrounding region. Household sizes were determined at each location from the survey. With this statistic, an estimate of the village populations was calculated (Table 1).

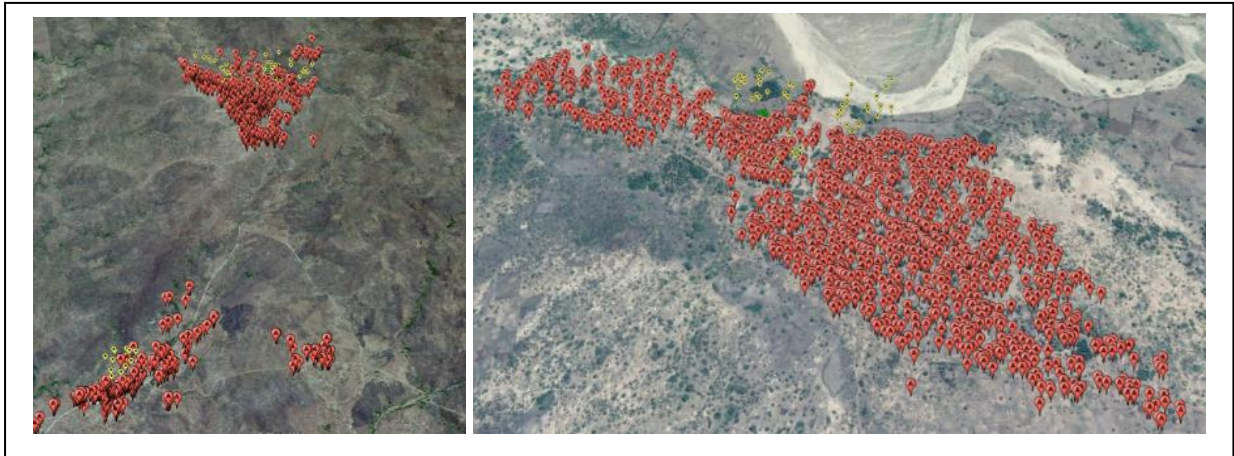


Figure 1: Kandeu and Mandrade Structures

All questionnaires were facilitated by a trained enumerator with prior experience in similar field work and piloted in a nearby village (not a SOGERV village) prior to deployment. Enumerators randomly selected households within the target village and heads of households were asked to respond on behalf the entire household. Target respondents for businesses were the owners, although employees were allowed to answer if the business owner was not available.

Table 1: Numbers of households and associated surveys for each community

Location	No. Households	Surveys completed	% of HH
Kandeu	473	52	11.0%
Mandrade	604	32	5.3%
Thendo	841	99	11.2%
Gola	1334	131	9.8%

The study makes the assumption that customer reported and itemised energy expenditures would be spent on replacement products. All financial values are reported in Malawi Kwacha (MWK) with the exchange rate to GBP at the time being 900:1.

3 Market Assessment

3.1 Incomes and Energy Expenditures of Households

The distributions for self-reported yearly incomes for households are shown for all locations in Figure 2 and energy expenses in Figure 3 as density plots. Overall, household annual incomes and energy expenditures are extremely low, though Kandeu and Mandrade are significantly lower on average than Gola and Thendo.

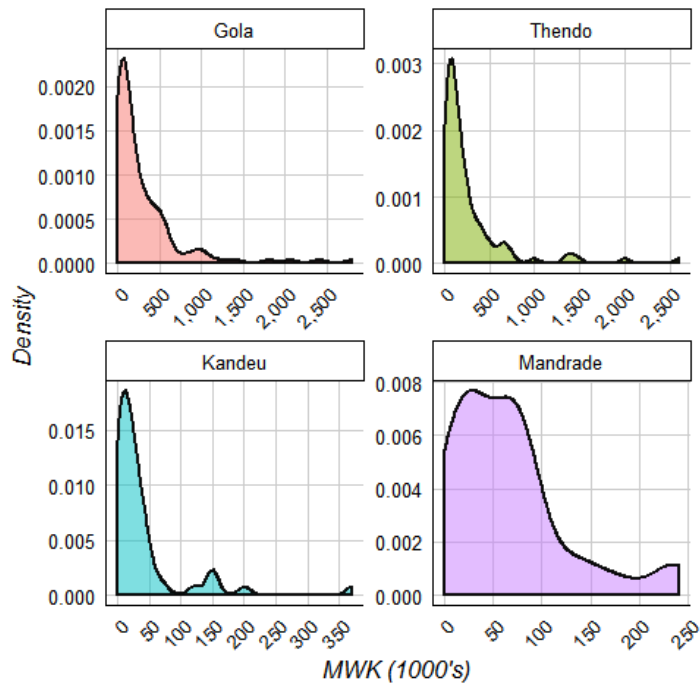


Figure 2: Yearly Income Density for Households in all Locations

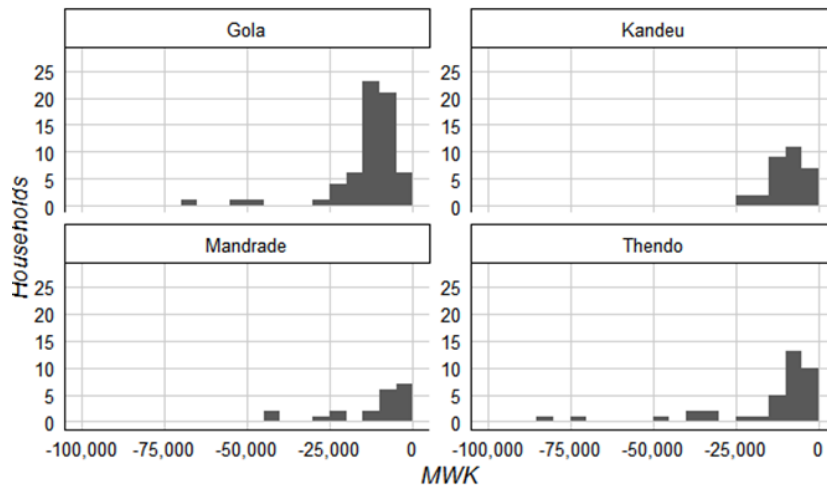


Figure 3: Annual Energy Expenses Distributions for all Locations

Households and businesses were also surveyed on their interest levels in various productive uses if they were to be established at each location. Households were asked whether they would be willing to pay for the services from each business. Businesses were asked a slightly different question: how well a business doing said activity would fare if it were established (or expanded) at the location, specifically in terms of its likelihood to be profitable. The results are shown in Figure 4 below. The squares represent the average response from businesses; the circle is the average response from households. The highest scoring productive uses were mobile phone charging, cold drinks, battery charging, entertainment, barbershop, metal shop and shop lighting.

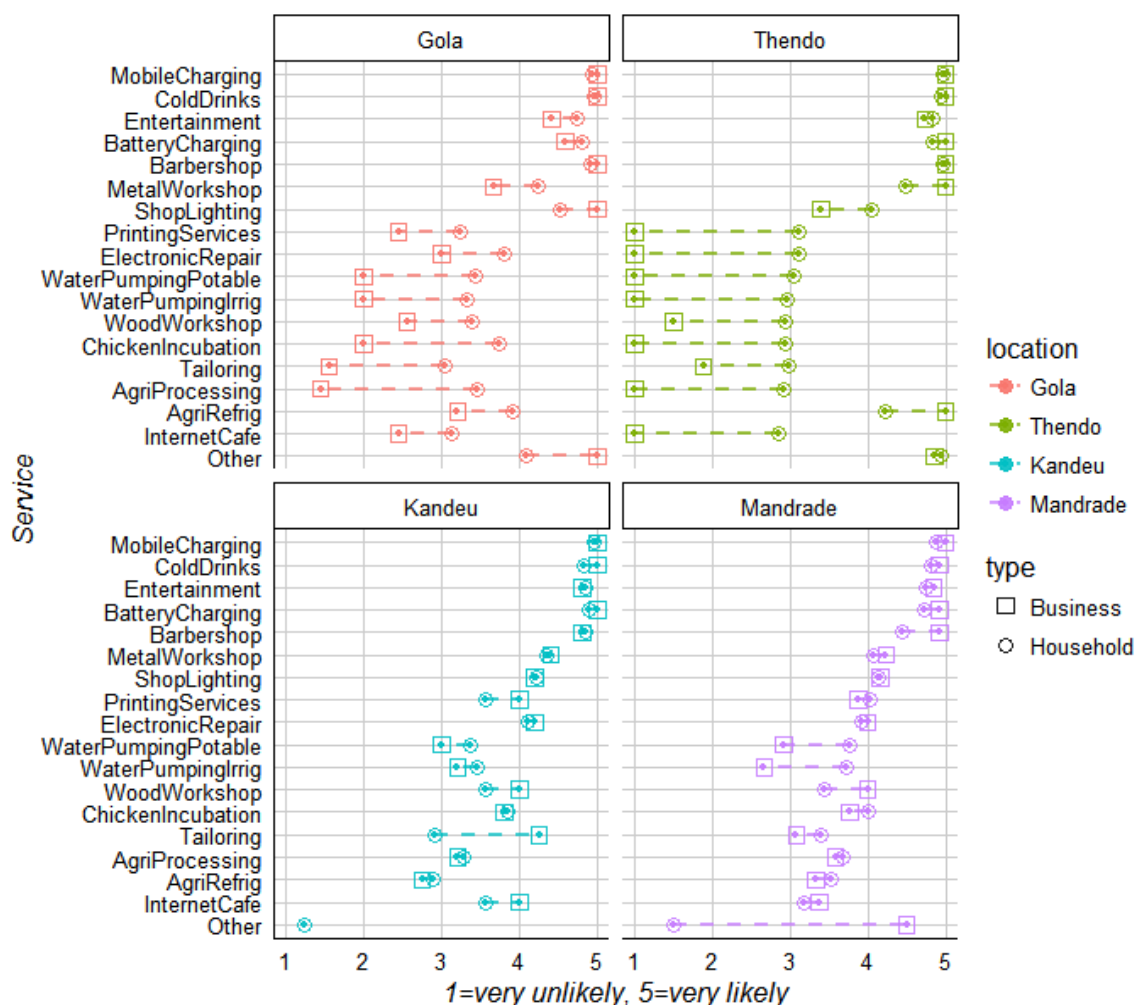


Figure 4: Interest in Energy Services for both Households and Businesses

3.2 Market Size Estimation

At all locations, it was established that the majority of consumers have very low yearly energy expenses and since the likely prices can be estimated using the products available to be deployed, the number of products and likely pricing mechanisms for this market could thus be estimated. To do this, a full population was estimated using the actual village size and the distributions of energy expenses in the village. The assumption was made that old products and fuel sources will be substituted for the new products introduced by the project, and hence, future energy expense would be equal to or greater than current expense.

The project identified four consumer products with well-established supply chains in Malawi (Table 2). Expected prices are given for each product, competitive with the local markets at the time. Although the intention was to offer ‘rent to buy’ arrangements, the analysis was simplified such that only the cash price and the yearly price for renting the products were considered.

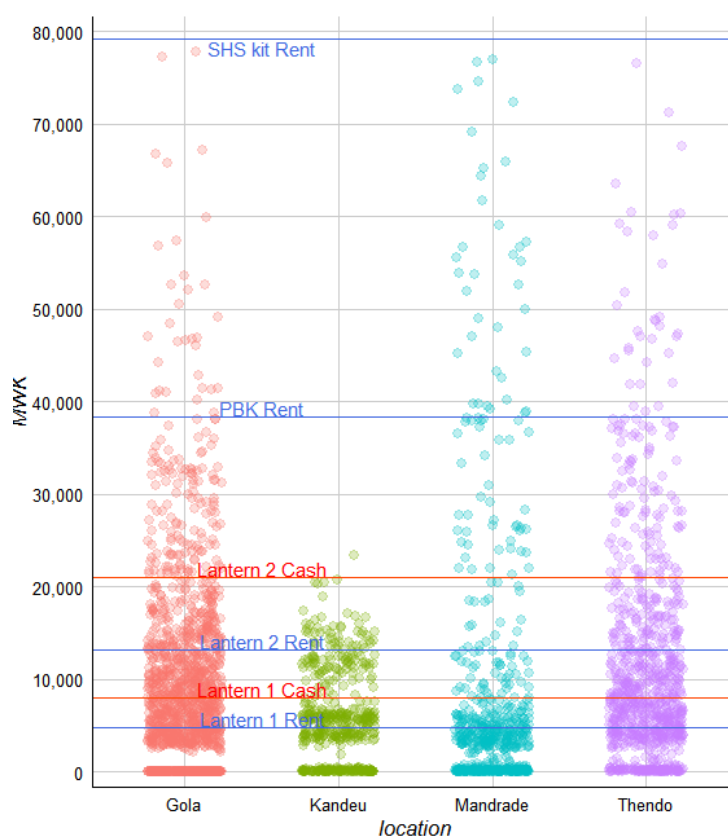
Table 2: Locally Available Consumer Products and Prices

Product and Description	Cash Price,	Rental Price (per year),
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	MWK	MWK
1 - Small Solar Lantern	8,000	4,800
2 - Small Solar Lantern with Mobile Charger	21,000	13,200
3 - Portable battery kit (PBK) with 2 lights and mobile phone charger	96,000	38,400
4 - DC Solar Home System (SHS) with 4 lights, mobile phone charging, radio, and task light	134,000	78,200

In Figure 5 these thresholds are drawn in as horizontal lines and labelled. In the graph, each dot represents one (simulated) household's energy expenses over the course of one year. These are drawn from the income distributions and scaled to the number of households in the village. The cash price is shown as red with the rental price in blue. The y-axis has been limited to a maximum of MWK80,000. As is clear, the higher priced goods are not affordable at a cash price. The rental price for Product 4 appears to be the maximum any one household would be able to afford.

Given these thresholds, the number of households who would purchase or rent the products can be estimated simply by summing those that fall between the thresholds. This is done on the cash purchase only scale and a renting only scale on the table below. The assumption used is that each household will purchase one product which is immediately at or below their budget. As is expected, the use of a financing arrangement (rental) means that considerably



more households gain access to the products.

Figure 5: Yearly Energy Expenditure and Product Cost Thresholds

3.3 Market Assessment Key Findings

The market assessment made the following recommendations to the project based on the analysis conducted above.

Household market:

- Product selection should err towards smaller systems which are less costly.
- Limited cash sales will be possible and in order to provide access to more functional products, a financing arrangement will need to be offered by the installed business which allows either for a rent-to-own or fee-for-service.
- As there was a preference and familiarity for cash sales, the less expensive products may be more appropriate for a rent-to-own arrangement with repayment terms that sufficiently lower the entry point.
- Although there were a few outliers, it is unexpected that many families will be able to purchase larger portable solar products (PSP) and solar home system (SHS) products outright.
- With the low level of competition, lack of existing renewable energy products, and willingness to pay, products targeted at the right entry point should be in high demand.

Productive use of energy:

- There was a 'high' willingness to pay for businesses offering mobile phone charging, cold drinks, battery charging, entertainment, barbershop, metal shop and shop lighting.
- Existing business owners predicted that businesses offering these services would be profitable.

4 Actual Business Outcomes

In this section, the recorded sales performance of the community energy businesses is set out for comparison with the market assessment forecast.

Following the project design stage, and building on the recommendations of the market assessment, each business implemented a 'Charging Station' powered by a 4kW PV array that providing the following services: PSP sales, mobile phone charging, battery charging. The business also provides stand-alone solar PV systems and 'wired connections' for monthly fees to a small number of nearby PUE businesses.

Figure 6 provides a summary of the total revenues for each business, categorized by the main product groups. The trading periods for each business are not uniform as the businesses commenced operating at different times; however, the cut-off date for collection of the data is the same in all cases: September 2018. The total revenues and trading period for each business is shown in Table 3.

Table 3: Trading period and total revenues for each business

Business Location	Date Started Trading	Total Revenues Recorded (MWK)
Mandrade	June 2017	9,013,212
Kandeu	April 2017	2,219,288
Gola	November 2017	2,815,395
Thendo	November 2017	2,935,648

It is immediately notable that for all businesses the majority of revenues realized has been through PSP sales. However, the best performing business (Mandrade) has also recorded high revenues related to portable batteries. The following sections will present further detail on the sale revenues, focussing on PSP sales and services for PUE businesses as the two main themes.

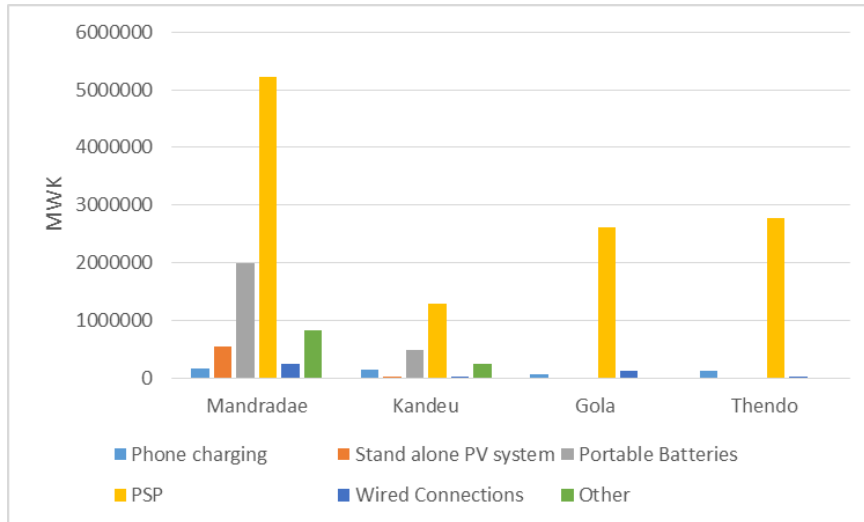


Figure 6: Total Sales Revenues per Product Type for All Businesses

4.1 PSP Business

Portable solar products are a major component of the business turnover. The products relate to the four market assessment categories as follows. Product Type 1: SM100, Velux, Sunking Pico. Product Type 2: D-Light, Sunking Boom, OV Pilot. Product Type 3: Sunking Home. Product Type 4: OV Camp.

4.1.1 Mandrade Community Energy Business

The numbers of each product sold and the associated sales revenues are shown in Figure 7 and Figure 8.

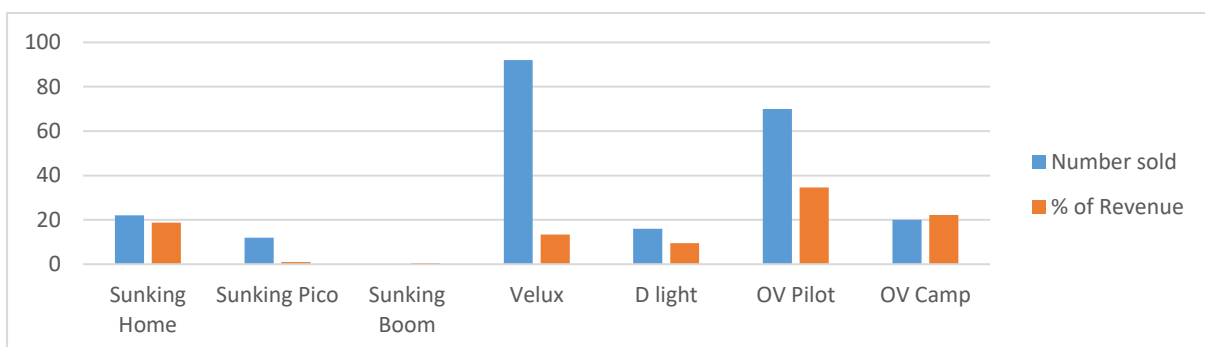


Figure 7: Business 1- PSP total sales

In terms of units sold, the smallest product dominates. However, the slightly more advanced OV pilot has also sold well and returns a greater revenue due to its higher price. Although sold in smaller quantities, the higher functionality, higher price ‘home’ systems (Sunking Home and OV Camp) account for a significant proportion of total sales revenue.

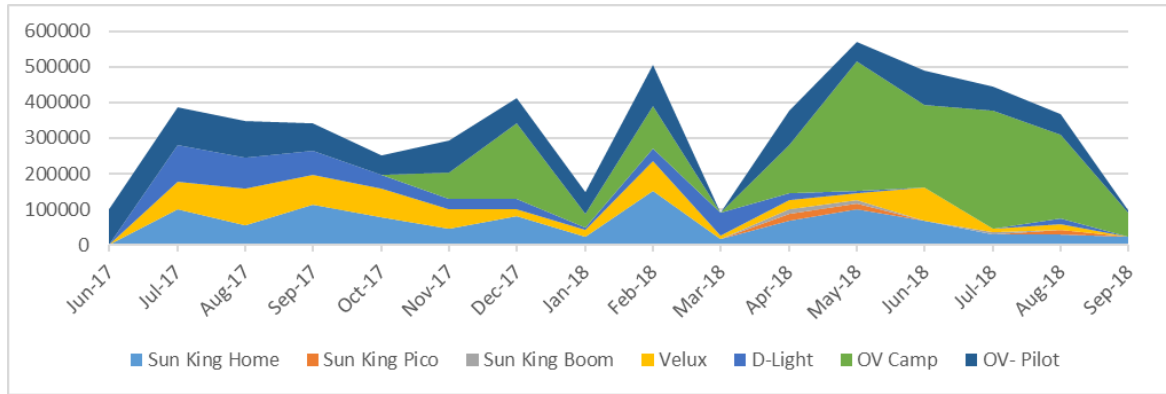


Figure 8: Business 1 - PSP sales revenues

4.1.2 Kandeu Community Energy Business

Portable solar products are a major component of the business turnover. The numbers of each product sold and the associated sales revenues are shown in Figure 9 and Figure 10.

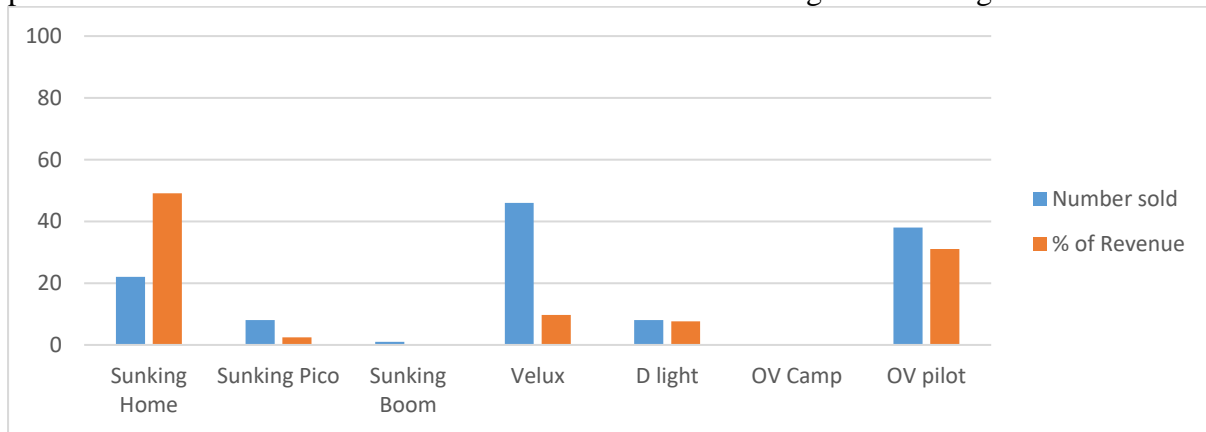


Figure 9: Business 2- PSP total sales

Again, in terms of units sold the smaller product dominates, with the OV pilot also selling well and returning a greater revenue due to its higher price. Although sold in smaller quantities, the higher functionality, higher price ‘home’ systems (Sunking Home) account for a significant proportion of total sales revenue.

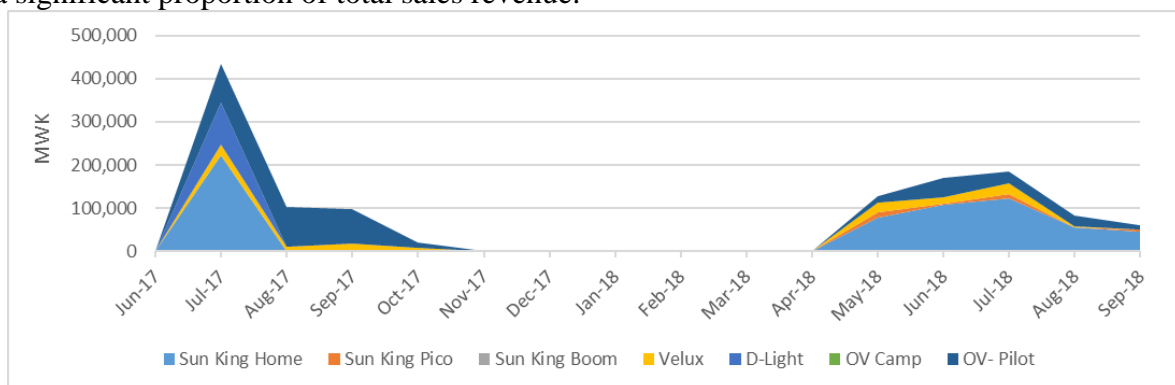


Figure 10: Business 2 - PSP sales revenues

4.1.3 Gola Community Energy Business

The numbers of each product sold and the associated sales revenues are shown in Figure 11 and Figure 12.

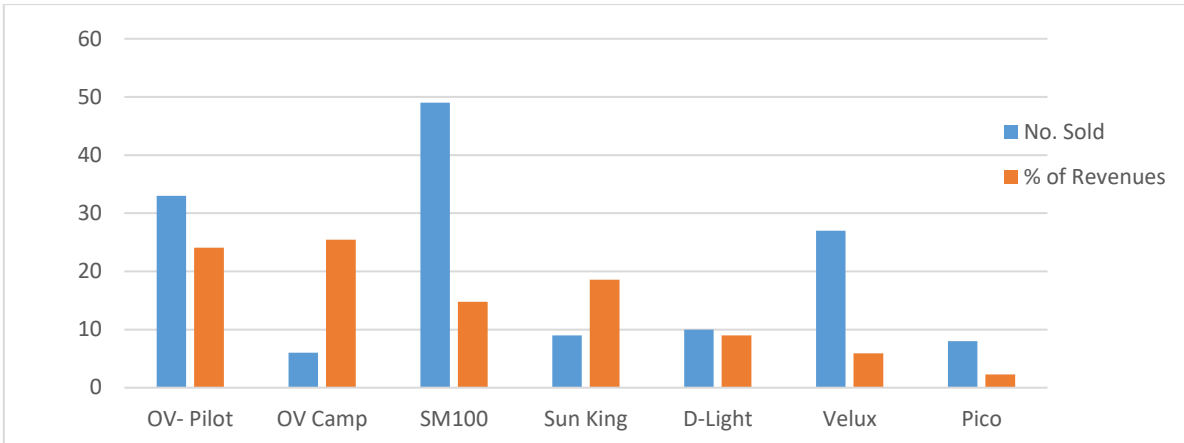


Figure 11: Business 3 - PSP total sales

The SM100 and the Velux dominate here in terms of units sold, due to being smaller and cheaper products. The OV pilot again sells well with its higher price returning a greater revenue. The higher price home systems (OV Camp and Sunking Home) offering higher functionality account for a significant proportion of total sales revenue despite being sold in smaller quantities.

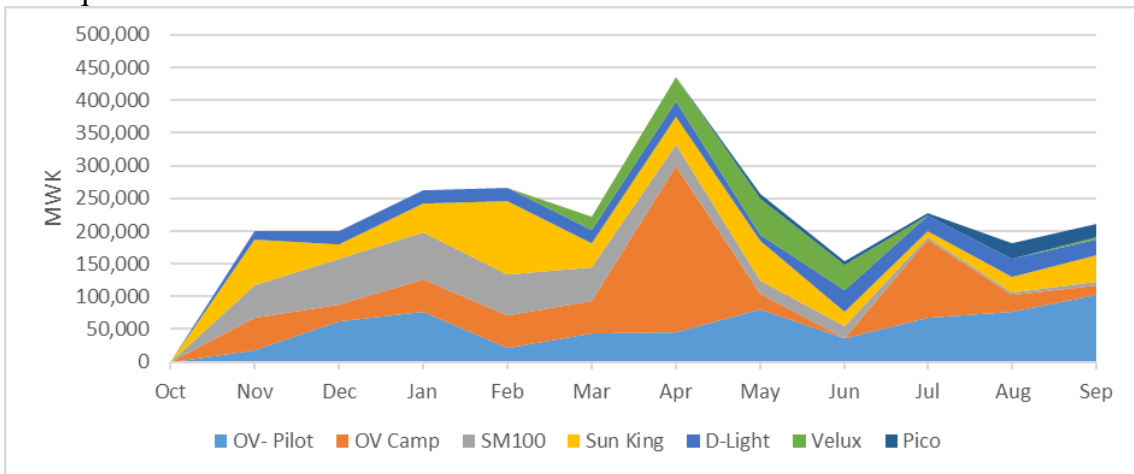


Figure 12: Business 3 - PSP sales revenues

4.1.4 Thendo Community Energy Business

The numbers of each product sold and the associated % of sales revenues are shown in Figure 13 and Figure 14.

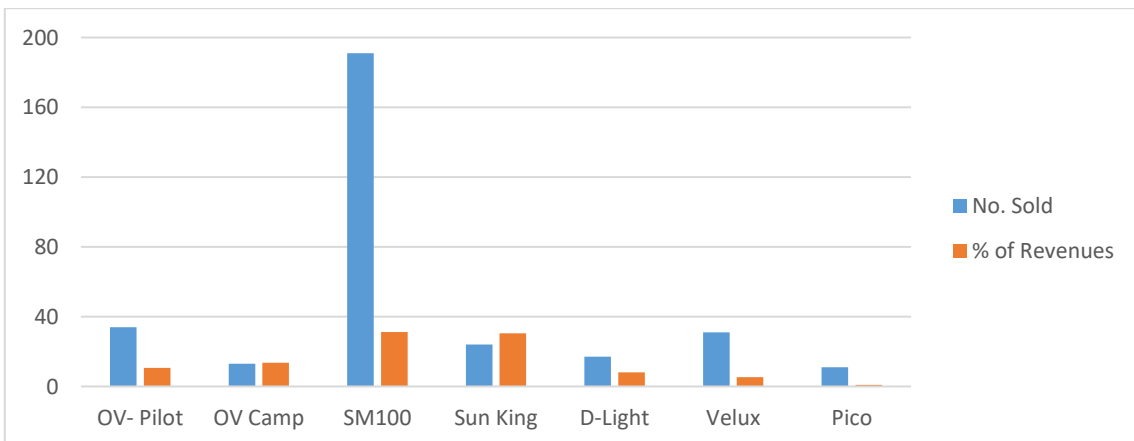


Figure 13: Business 4 - PSP total sales

As with the other businesses, the low cost smaller products dominate, in this case the SM100, with higher price home systems (OV Camp and Sunking Home) accounting for a significant proportion of total sales revenue.

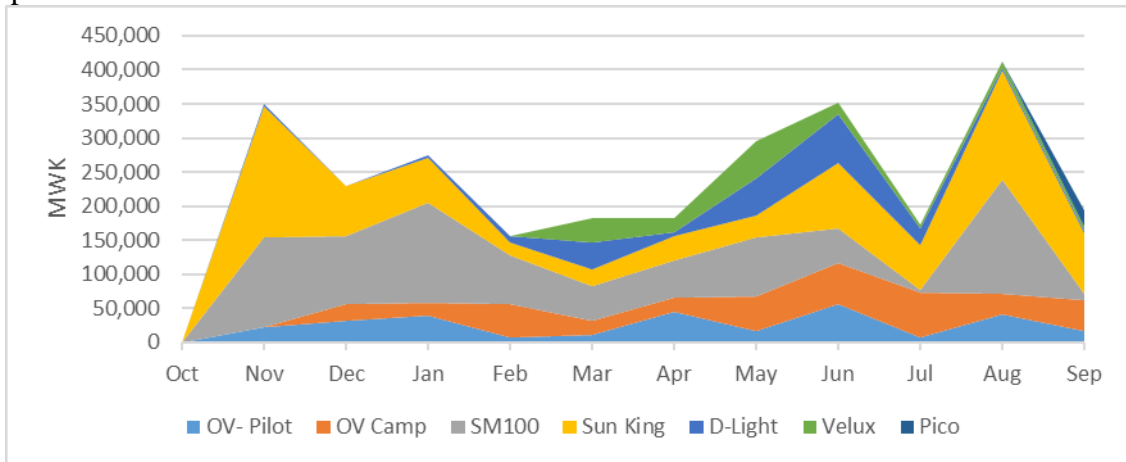


Figure 14: Business 4 - PSP sales revenues

4.2 PUE Businesses

Mandrade initially offered the rental of ‘large’ or ‘small’ stand-alone solar PV systems to local businesses priced at MWK15,000 and MWK20,000 respectively. Three businesses signed up for systems but one failed to maintain payments, others complained that pricing was too high. By Sept 2018 two ‘small’ systems were remaining, each paying MWK13,000, one hardware shop and one barber/cold drinks shop. After establishing the businesses in the village, entrepreneurs started to co-locate with the Charging Station and request a wired connection. This was offered and three PUE businesses connected paying a flat rate fee of MWK10,000 per month: a barbershop, a video show and a cold drinks kiosk.

Kandeu also offered the rental of ‘large’ or ‘small’ stand-alone solar PV systems to local businesses priced at MWK15,000 and MWK 20,000 each. Two businesses signed up for systems but both failed to maintain payments, complaining that pricing was too high. By Sept 2018, both systems had been removed. Wired connections proved more attractive and two PUE businesses connected, paying a flat rate fee of MWK10,000 per month: a barber shop and a video show.

Based on experiences in Kandeu and Mandrade, neither Gola nor Thendo opted for stand-alone solar PV system options, finding wired connections more attractive. In Gola, four PUE businesses connected, paying a flat rate fee of MWK10,000 per month: a barber shop, a grocery, a cold drinks kiosk and a video show. In Thendo two PUE businesses connected, paying a flat rate fee of MWK10,000 per month – a barber shop, and a cold drinks kiosk.

5 Comparing MA Predictions with Actual Sales Figures

5.1 PSP Sales

The market assessment predicted that smaller products would be most attractive. This has been proven to be correct, evidenced by the dominance of portable solar products in the actual sales data. The figures are compared in Table 4 below. The most notable points are firstly the lower costs achieved for product cash price (reflecting the dynamically moving sector), and secondly that a ‘rent to buy’ option was implemented with approximately 10% price premium. It is noted that the business operators report almost 90% of sales are ‘rent to buy’. There is an exception with the largest product as operators reported that customers

were often unable to afford the three-month repayment and usually instalments were paid over 6 months totalling the cash price with no premium.

Table 4: Comparison of market assessment predictions and implemented sales for PSP

Product and Description	Market Assessment		Implemented	
	Cash Price, MWK	Rental Price (per year), MWK	Cash Price, MWK	Monthly installments (3 of) MWK
1 - Small Solar Lantern	8,000	4,800	5,000 - 6,500	1,840-2,400
2 - Small Solar Lantern with Mobile Charger	21,000	13,200	19,000 – 25,000	7,200 – 9,200
3 - Portable Solar Product with panel, battery, 2 lights and mobile phone charger	96,000	38,400	58,000	21,000
4 - DC Solar Home System (SHS) with 4 lights, mobile phone charging, radio, and task light	134,000	78,200	140,000	46,700

The market assessment effectively predicted the maximum number of cash sales or rentals for each product type in each location. These are compared with actual sales in Table 5 (market assessment figures are shown as (cash/rent). Actual sales are recognised to be mostly ‘rent to buy’ monthly instalment sales, so the comparison is not exactly like for like. It could be argued that the actual sales figures should therefore be somewhere between the two, approaching the rental prediction.

It appears that for the smallest product type, the market in Mandrade was well estimated and is approaching saturation (this matches well with verbal reports from the operator that he has been travelling outside the village to maintain sales). The Gola Product 1 market appears significantly overestimated. Sales have been prolific in Thendo and are also approaching the top end of the predicted market. For Product 2, Kandeu and Mandrade appear well estimated and approaching saturation, while Gola and Thendo seem underestimated. The market for Product 3 has been underestimated in Kandeu. Mandrade and Thendo are achieving reasonable sales in line with predictions, but Gola is under performing. The market for Product 4 has been largely underestimated with Mandrade and Thendo performing well above expectation and Gola also achieving sales near the maximum predicted.

Table 5: Comparison of market assessment predictions and implemented rental income for PSP

Product Type	Kandeu		Mandrade		Gola		Thendo	
	MA	Actual	MA	Actual	MA	Actual	MA	Actual
1 - Small Solar Lantern	142/206	55	66/126	104	440/458	84	270/327	233
2 - Small Solar Lantern with Mobile Charger/radio	5/62	46	63/103	86	170/325	43	134/208	51
3 - Medium Portable Solar Kit	0	22	0/54	22	6/36	9	0/41	24
4 - Large Portable Solar Kit	0	0	0/9	20	0/10	6	0/4	13

It is noteworthy that the numbers of units reported as sold do not align fully with the sales revenues reported. Namely, although Mandrade has reported approximately twice the PSP income of Thendo, the sales numbers are: 104/233, 86/51, 22/24, 20/13 for the respective products 1 through 4. These sales figures would imply similar total revenues; however, the data does not allow this to be fully explored. A possible explanation is that Mandrade has achieved more cash sales and/or recovered instalment payments more successfully, banking more income from units ‘sold’.

5.2 Productive Uses of Energy

The market assessment highlighted a ‘top eight’ of PUE prospects, which are discussed in turn below:

5.2.1 Mobile phone charging

The business is selling products that enable phone charging to be undertaken by households and other businesses; however, the extent of this activity is not being tracked formally by the project. Each charging station has averaged about 200 ‘charges’ per month. However, the low fee for a charge (MWK 70) means that mobile phone charging has provided a minimal income stream to the Charging Stations. The continued presence of customers for the charging station does imply that there is still a significant market for other entrepreneurs to target (with a larger PSP product for example).

5.2.2 Entertainment, cold drinks and barbershops

These three PUE businesses make up the bulk of the entrepreneurs paying for services: four cold drink shops and five barbershops. Only one of those uses a stand-alone PV system. Three video show customers have been established by the Charging Stations.

5.2.3 Charging batteries

This service has been exclusive to the Mandrade and Kandeu Charging Stations. This is reported to be primarily due to delay in supply of appropriate battery kits and charger units. The sales at Mandrade are dominated by battery rental and sales rather than charging. The business operator identified that there was demand for the flexibility of a simple battery instead of PSP and sourced these for retail. There appears to be a potentially significant market for this service.

5.2.4 Metal workshops

No metal workshops were established as neither the Charging Station or stand-alone PV systems are able to meet the massive power requirements.

5.2.5 Providing shop lighting

Only one shop has maintained the rental of PV system for shop lighting. There is a perception from the business operators that many small entrepreneurs are using portable PSP for their basic shop lighting which is deemed a more economical solution.

5.2.6 Agricultural refrigeration

No agricultural refrigeration has been established. Determining the reasons for this are outside the scope of this work; however, it can be speculated that this would require input from an agricultural development initiative to establish a new farming mind-set and route to market.

6 Conclusions

The market assessment described in this paper provided a clear direction towards smaller, more affordable products that are portable and provide simple lighting, phone charging and perhaps radio services. The established businesses have tested this market with a range of

products and have found that sales are largely in line with market assessment product predictions. However, a larger market than predicted appears to exist and there is more appetite for the larger ‘household-scale’ portable products than previously thought. In addition, the market assessment indicated an opportunity for PUE services in the community. There has been a small uptake on the offered energy provisions from local entrepreneurs with cold drink sales, barbershops, video shows and shop lighting. The maximum monthly fee the entrepreneurs will sustain is MWK13,000, and only two entrepreneurs have sustained payment for a stand-alone PV system, while the others sought ‘ad-hoc’ wired connections. Battery charging at the Charging Stations has been popular where the service is available, suggesting that further households are meeting basic electricity service needs via this method instead of purchasing PSP.

With the large majority of revenues being obtained through PSP sales and battery sales and rental, the value or need for the 4kW Charging Station is questionable. The income streams that require on-site power production could be estimated at best as MWK40,000 per month from four wired connections and MWK4,000 per month for battery charging. To fully utilise the potential of the on-site generation it appears that further effort to initiate a range of co-located PUE is required, or alternatively, inclusion of some localised distribution networks to connect the charging stations with nearby household and business lighting and basic energy service demand, suggesting a solar micro-grid approach would be the logical next step.

The findings of the paper are relevant for energy practitioners, decision makers and planners in developing countries. The value of in-depth market assessments has been shown, with the recommendations of particular import to practitioners looking to conduct similar projects within Malawi. Finally, the importance of economic sustainability of off-grid solar PV businesses has been highlighted as a key priority for achieving SDG7.

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Overcoming the bottleneck of weak grids: Reaching higher tiers of electrification with Solar Home Systems for increased supply reliability

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Abstract

Electrification efforts have long been a centralized, politicized and bureaucratic process heavily dependent on central grid extension. However, grid connection may not guarantee reliable supply and even grid-connected households can remain in lower tiers of electrification. By promoting the integration of solar home systems (SHS) in electrification plans, consumers could bridge blackout times and climb the ladder of electrification. To evaluate this potential, we perform a case study in Gauriganj district in Nepal based on primary survey data (2018), including real-time measurements of actual blackout occurrences. A self-coded open-source simulation tool based on the Open Energy Modelling Framework is applied to determine the optimal grid-supporting SHS capacities. For households of lower electricity demand (Tier 2) an SHS of 70 Wp PV and 215 Wh battery is the cheapest option to ensure reliably electricity supply at 24.8 ct/kWh, supplying 25 % of daily demand unmet by the national grid. A household with higher electricity demand (Tier 4) requires a SHS of 290 Wp PV and 2 kWh battery to provide backup for 28% of its demand currently not met by the grid, resulting in costs of 23.4 ct/kWh. Encouraging these investments will support efforts towards achieving SDG7.

Keywords: Electrification, SHS, Blackouts, Nepal

Introduction

Electrification in general

It is widely recognized that access to modern forms of energy is an essential prerequisite for overcoming poverty and promoting human development [1]. Recognizing such benefits, the United Nations (UN) defined Sustainable Development Goal 7 (SDG7) [2], aiming at access to affordable, reliable, sustainable and modern energy for everyone by 2030.

Recent ramping up of efforts to improve household access to modern energy supply have posed challenges to central grid infrastructure reliability. Generation capacities and transmission infrastructure may not keep up with the newly built connections nor existing consumer's growing electricity demand. This imbalance leads to low quality electricity supply and blackouts [3][4]. As a result, households remain without proper and reliable supply. In the last decades, decentralized solutions such as mini-grids and solar home systems (SHS) have emerged as a viable complementary technology. Independently of top-down electrification efforts, some consumers already pursue these solutions either to gain access for the first time or to increase supply reliability.

To measure and track progress of SDG7, the multi-tier framework (MTF) has been developed. In contrast to binary metrics, it measures access to electricity according to seven attributes, namely peak available capacity, duration of service, affordability, legality, quality of voltage, reliability and health and safety [5]. Drawing from this metric, household supply can be categorized and the potential of backup battery and SHS – solar PV combined with batteries - can be evaluated to improve the conditions of grid-connected households.

Key questions of applying decentral solutions within grid- connected households are: (1) How far can the reliability be increased? (2) What are optimal system designs? What costs are assigned to the increased reliability? We conducted a case study in Nepal based on primary survey data and real-time grid availability measurements (2018) to address these questions. Applying a self-coded open-source simulation tool based on the Open Energy Modelling Framework [6] to two representative demand profiles of the case study households we determined optimal grid-supporting SHS capacities and calculated the respective effects on reliability and on costs.

Electrification in Nepal

Nepal is a landlocked country at the foot of the Himalayas, between the People's Republic of China and India. It has a total population of 26.5 million [7] and is - based on the per capita gross domestic product - one of the least developed countries in South East Asia [8]. Around 81 % of the total population lives in rural areas, with only 72 % of the people having access to electricity in these areas compared to 97 % in the urban areas [9]. The national grid has a low supply reliability: On average 8.7 outages per month occur lasting about 3.6 h each (2013) [10].

As Nepal has abundant hydro-power and solar energy resources the government promotes programs for the electrification of rural areas based on renewable energies [11]. Both grid-strengthening and off-grid electrification with renewables is pursued, the latter mostly in the form of off-grid micro-hydro mini-grids and solar home systems (SHS).

The location of our case study is the rural municipality of Gauriganj, in Province 1, far-eastern Nepal. It is characterized by a particularly high penetration of the grid (85 % of households are estimated to be connected to the national grid [12]), while at the same time experiencing frequent grid outages.

Measurements on national grid availability

Real-time field measurements were applied to generate representative hourly profiles for grid availability in the case study. For that, five Electricity Supply Monitoring Initiative (ESMI)

data measurement devices [13] were installed across five locations in Gauriganj municipality. Specific locations were selected to represent peri-urban and rural areas of the municipality, as well as both central branches and fringes of the grid (see Figure A1 in appendix). The installation took place in collaboration with the GIZ Nepal – Renewable Energy for Rural Areas Programme (GIZ-RERA). The measurement campaign was conducted for one full month, from July 1st 2018 until July 31st 2018. The devices measured grid voltage at a household socket in 1-minute resolution.

In order to further use the measured data, for each ESMI sensor data timeseries, the 1-minute grid voltage data needs to be converted into a binary grid availability variable. This is based on the assumption that electricity from the grid can be used to power appliances if the voltage stays between 180 and 240 V. Thus, voltage levels in that range indicate grid availability, voltages outside that range indicate blackouts. Then, the hourly average of the binary grid availability variable is calculated to reach the needed time scale of hourly profiles. Finally, the binary ESMI sensor datasets are merged, resulting in municipality-wide binary grid availability at 1-hour resolution for the month of July. From that, the likelihood of grid availability at each hour of a typical day is derived by grouping the resulting data set by hour of the day and taking the simple average. This empirical grid reliability profile, which is visualized in Figure 1 (left), is eventually used as an input for the stochastic grid reliability profile development, resulting in a time series of Boolean values (1 = grid is available; 0 = grid is not available) for each hour of one reference year.

When comparing the synthetic grid reliability against the measured profile for the month of July 2018 a reasonable fit is found (comp. Figure 1 right). Still, there are limitations to this methodology, as the measurements only spread over a single month and seasonal or annual variations of blackout occurrences are not considered. Further, measurement errors might be included in the data series as households were told not to unplug the ESMI but still may have done so. This random effect is reduced by the fact that we use five sensors and aggregate the data across all of these.

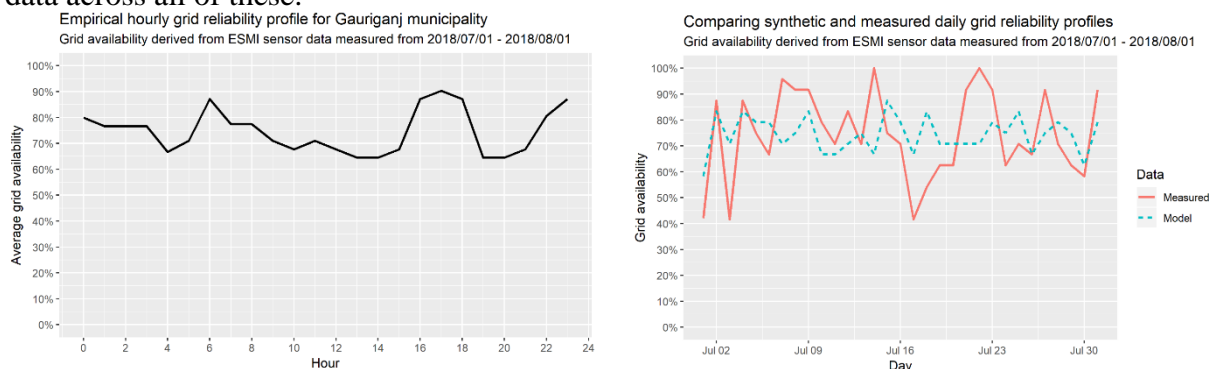


Figure 1. Measured hourly grid reliability over a typical day (left) and stochastic grid reliability model validation (right)

Surveys and demand estimation

Survey design and implementation

In early 2018, funded by GIZ Nepal under the RERA program in collaboration with the Alternative Energy Promotion Centre (AEPC), the Reiner Lemoine Institut (RLI) developed a detailed household survey based on the MTF approach and adjusted it to the realities of the Nepalese context [12]. The main objective of the survey was the collection of primary data to support energy planning through the assessment of the current energy access status, as well as of the energy demand and willingness to pay across existing and potential energy users in the

context of rural municipalities of Nepal [12] [14]. In addition, households were asked to report all the appliances they currently owned and used within their dwelling. The survey was applied across 14 municipalities of Province 1 and 7 in rural Nepal between March and August 2018. As a result of the implemented sampling strategy, each sample of 400 households was representative at the municipal level. This study focuses solely on the municipality of Guariganj.

Demand profile generation

Representative basic and high demand household consumption profiles were characterized based on the surveyed ownership rates of typical appliances. The basic consumption profile includes all appliances owned by more than 50 % of the respondents. The high consumption profile includes all appliances that are owned by at least 15 % of the respondents. In alignment with the energy access levels defined in the MTF these two profiles are labelled Tier 2 and Tier 4 in the following sections. The necessary assumptions regarding the appliances, including the quantity of a type owned by a household as well as AC and DC power ratings were defined based on a market study and literature review (see Table A1 in appendix).

A load profile was generated with the aid of a stochastic load modeller, which is written in R. For each application the input consists of its availability window as well as the range of number of occurrences in the course of one day and each occurrence’s range of utilization duration. The parameters were defined based on a literature review on similar tools and appliance usages [15][16].

The stochastic load modeller determines how often an appliance is used as well as the durations and starting time, from which it generates a 24-hour load profile. To account for high-power appliances being used for shorter periods, the profile is generated for 30-minute timesteps and then averaged to hourly values. The flowchart in Figure 2 conveys the methodology employed for a single appliance. The demand profile of a household results from the accumulation of the load profiles of each of its appliances. To achieve an annual load profile this process is repeated automatically for each day in the year.

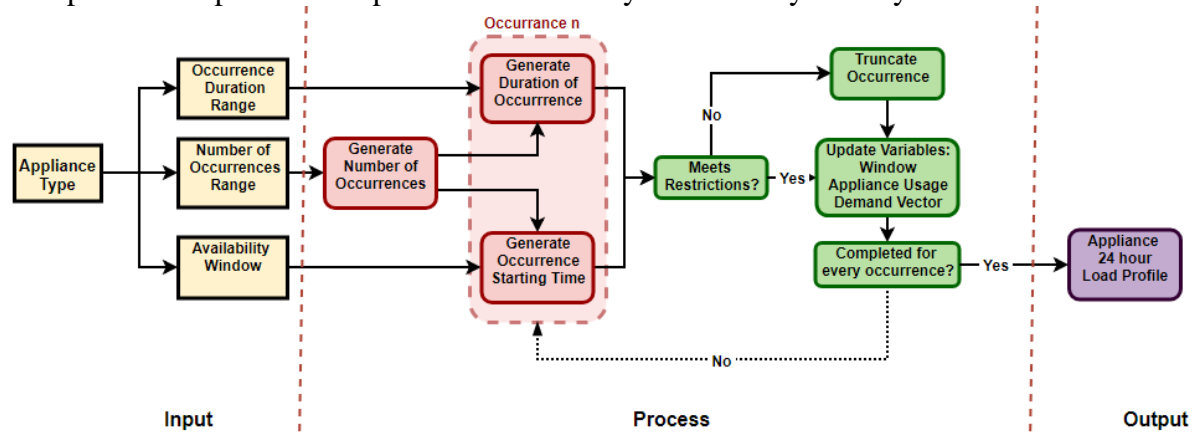


Figure 2. Load modeller flow chart for one appliance.

The generated profiles confirm the definition of basic and high demand households as Tier 2 and Tier 4 according to the MTF based on their daily average AC demand: The average consumption of the basic household amounts to 394 Wh AC/d (152 Wh DC/d), and the high demand profile amounts 3929 Wh AC/d (1400 Wh DC/d). Tier 2 is defined as consumption of around 200 Wh per day and Tier 4 is defined as consumption of around 3,400 Wh per day. The DC consumption profiles generated are far lower than the AC profiles due to the assumed efficiency of DC appliances. Figure 3 shows an example DC demand profile of a Tier 2 household for a 3-day period in 30-minute timesteps. The appliances are turned on

randomly in their assigned availability windows and each of its days display a different load curve, mirroring real life variability.

Still, the stochastic load modeller has limitations in its methods and application. Firstly, an hourly demand profile is only able to emulate the utilization of high-power appliances on a rather simplified level, either underestimating peak demand or overestimating consumption. Additionally, no seasonal variation has been included in the appliance usage parameters. Finally, while the availability windows and usage parameters are based on the survey data, it could be argued that there are still several levels of uncertainty which remain unaccounted for.

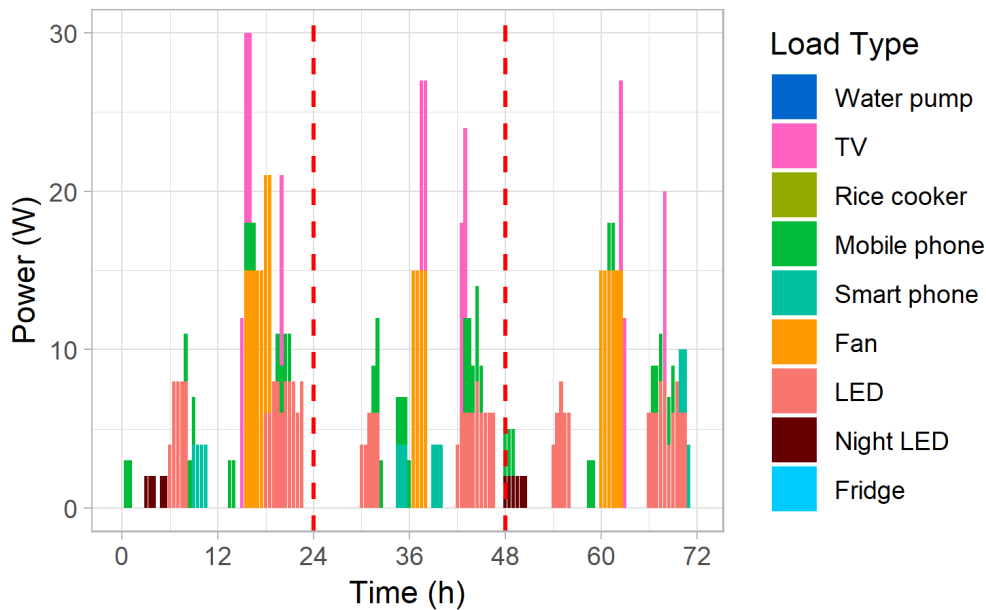


Figure 3. DC demand profile of Tier 2 in 30-minute timesteps.

Simulating the energy systems of the case study

Background of simulation tool

To determine the optimal SHS capacities ensuring supply reliability of grid-connected households in Nepal, a self-coded simulation tool is utilized. It is based on the python-based Open Energy Modelling Framework (oemof) [6], which offers a platform to model various energy systems. Each model created with oemof builds up on basic components, consisting of sinks, sources, transformers and storages, all connected through uni-lateral flows with respective busses. Each component has several parameters describing its behavior and assigning costs or efficiencies to its flows. oemof transposes the model to a set of linear equations. The problem can then be optimized using different solvers resulting in the cost-optimal solution.

The general energy system created with the case study's simulation tool is displayed in Figure 4. **Error! Reference source not found.** The components – grid connection, PV, battery, AC or DC demand, inverters and rectifiers – are included according to the respective scenario definition. While the optimal SHS capacities – installed capacity of PV panels and battery – are a direct simulation output, other indicators are calculated to ease scenario comparison.

The supply reliability η is the share of annual electricity demand E_{dem} and supplied electricity E_{spl} :

$$\eta = \frac{E_{spl}}{E_{dem}}$$

The renewable factor RF is the ratio of electricity from renewable (PV) sources E_{RES} and fossil (grid) consumption E_{fossil} :

$$RF = \frac{E_{RES}}{E_{RES} + E_{fossil}}$$

In addition to that, the levelized cost of electricity (LCOE) is calculated. It is based on the net present value (NPV) which monetizes all cash flows connected to the supply system, including expenditures for electricity consumption from the grid. The capital recovery factor CRF translates the NPV into an annuity.

$$LCOE = \frac{NPV \cdot CRF}{E_{spl}}$$

It must be emphasized that the actual supplied electricity is used as the reference value, not the initially intended consumption. This implies an interdependence between system reliability factor and LCOE, but avoids that unreliable systems are assigned an unreasonable low LCOE solely based on their high (but not supplied) demand.

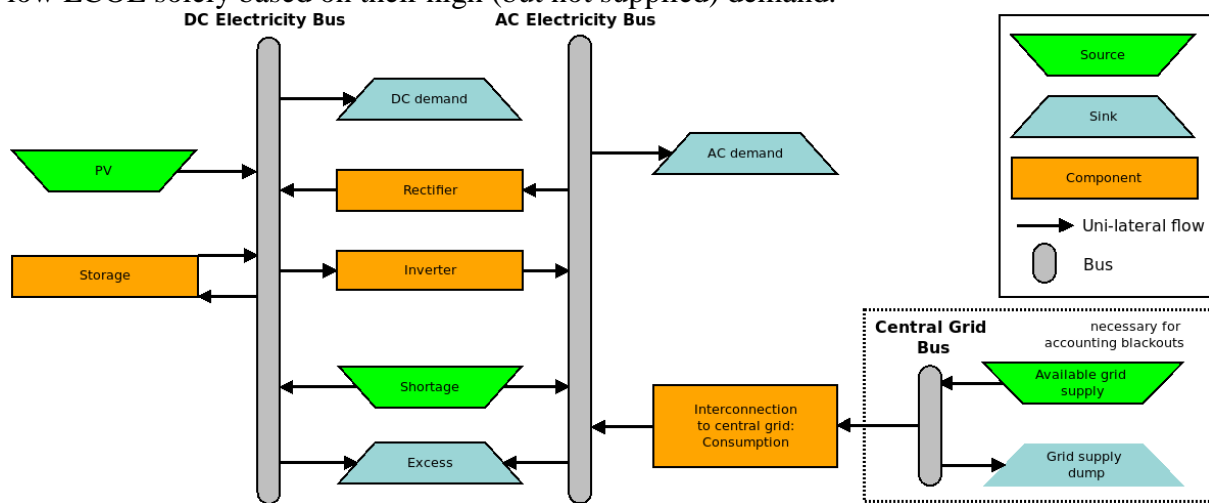


Figure 4. Energy system modelled with oemof-based simulation tool.

Components are (de-) activated depending on the scenario analyzed.

Scenario development

The potential of SHS as a backup system to the national grid to ensure 100 % supply reliability is evaluated through several scenarios:

1. Sole *national grid*, describing the status-quo of electricity supply. Electricity is solely supplied by the national grid and blackouts can occur.
2. *Backup battery*, which is charged fully through an inverter when the grid is available and are only utilized when the grid is offline, utilizing a rectifier. This type of backup system common throughout Nepal and colloquially called “inverters”.
3. *Backup SHS (PV and battery)*, in which the battery is solely charged through the PV system, but not the national grid. In case of a blackout, users manually...
 - a) switch on an inverter that allows battery discharge to meet AC demand.
 - b) change their demand from AC to DC appliances.
4. *Off-grid SHS (PV and battery)* as a form of decentralized supply of...
 - a) DC demand.
 - b) AC demand.

Assumptions and input data

To allow the simulation of above defined scenarios, two additional constraints were included in the oemof simulation tool. Firstly, the inverter of each grid-connected system can only be used when the grid is experiencing a blackout, ensuring that the components are only used as backup devices but not as electricity supply option equal to grid consumption. Secondly, a constraint for forced battery charge is introduced for the backup battery in “inverter” mode, avoiding oemof’s built-in dispatch optimization method, which uses perfect foresight, and imitating real-life operating conditions.

The input for the simulation consists of above generated grid availability and demand profile, a specific solar generation timeseries, system component costs as well as technical parameters (see Table A2 and Table A3 in appendix).

The grid connection presented in scenarios 1) to 3) is assumed to have already taken place and connection costs are not included in the economic calculations. For scenario 3b) the installation of an additional DC circuit including appliances is necessary and included in the project costs (Tier 2: 30 €, Tier 4: 60 €, lifetime of 10 years). A project duration of 20 years is assumed and a discount factor of 9 %. As the electricity tariff of the Nepalese national grid depends on the monthly consumption [17], an electricity price of 3.2 ct/kWh is used for Tier 2 and of 7.9 ct/kWh for Tier 4.

Simulation results for different supply scenarios

Simulating the scenarios of the case study determines the optimal backup system capacities, their reliability, renewable factor and LCOE. A SHS as a backup system appears to be the cheapest option for reliable supply. A summary of the capacities as well as cost indicators calculated for each scenario can be found in Table 1 for Tier 2 and Table 2 for Tier 4 and are discussed in the following.

Supply solely through the main grid effects daily life heavily due to blackouts. The reliability of AC demand supply for Tier 2 consumers lies at 74.8 %, while Tier 4 households have a slightly lower supply reliability of 72.1 %.

An autonomous off-grid system would be the most expensive supply solution. For a Tier 2 consumer AC supply could be realized at 50.1 ct/kWh and DC supply at 46.6 ct/kWh. A Tier 4 consumer would face an LCOE of 46.9 ct/kWh for DC supply, while AC supply be possible at 39.3 ct/kWh. This is however resulting from the huge discrepancy between AC and DC load profiles. It is important to note that installing an AC system, even though cheaper per supplied kWh, would have more than doubled the NPV as installing a DC SHS delivering the same electricity-based services.

A battery backup system is less expensive than an off-grid SHS. Reliable supply can be reached with a battery capacity of 370 Wh for a Tier 2 consumer with an LCOE of 31.2 ct/kWh and for a Tier 4 consumer with 2.6 kWh battery capacity at 28.5 ct/kWh.

Backup SHS appear as the solution with the lowest costs to ensure reliable electricity access. Using it to supply AC demand leads to an LCOE of 24.8 ct/kWh for Tier 2 households at an installed capacity of about 70 Wp PV and 215 Wh battery, resulting in a renewable share of about 50 %. A Tier 4 consumer can be lifted to reliable electricity access by installing 289 Wp PV and 2 kWh battery at 23.4 ct/kWh with a renewable share of 30 %. When installing a secondary electricity circuit with DC appliances, which are only used during blackout times, the costs of a SHS backup system can be decreased further (Tier 2: 21.1 ct/kWh, Tier 4: 18.4 ct/kWh). This tendency should be evaluated in future studies with a greater level of detail regarding the additional necessary investments.

Table 1. Optimized systems and their performance - Tier 2. *) Not reliable supply solution.

Scenario	Topology	Demand	LCOE (ct/kWh)	Annuity (€/a)	Capacity PV (Wp)	Capacity Battery (Wh)
1	Sole main grid*	AC	3.1	3.4	n.a.	n.a.
2	Backup battery	AC	31.2	44.8	n.a.	369
3a	Backup SHS	AC	24.8	35.7	70	216
3b	Backup SHS	AC + DC	21.1	30.1	69	212
4a	Off-grid SHS	DC	46.6	25.9	102	202
4b	Off-grid SHS	AC	50.1	72.1	259	596

Table 2. Optimized systems and their performance – Tier 4. *) Not reliable supply solution.

Scenario	Topology	Demand	LCOE (ct/kWh)	Annuity (€/a)	Capacity PV (Wp)	Capacity Battery (Wh)
1	Sole main grid*	AC	7.7	80.5	n.a.	n.a.
2	Backup battery	AC	28.5	411.1	n.a.	2612
3a	Backup SHS	AC	23.4	337.3	289	1995
3b	Backup SHS	AC + DC	18.4	264.0	284	1955
4a	Off-grid SHS	DC	46.9	240.3	791	1892
4b	Off-grid SHS	AC	39.3	566.7	2296	4470

Still, the investments necessary to ensure 100 % supply reliability might be too high to be implemented by the consumers. As system design with renewable energy tends to require high capacities to buffer variabilities, a sensitivity analysis was performed evaluating the influence of allowed annual supply shortage, and thus, intentionally decreased reliability.

It can be observed that allowing a 99 % supply reliability can decrease the LCOE greatly (see Figure 5). The annual costs of the cheapest option, the backup SHS for DC supply in case of blackouts, decrease from 30.1 €/a to 20.8 €/a at 14.7 ct/kWh for Tier 2 and from 264 €/a to 192.1 €/a at 13.5 ct/kWh for Tier 4. A large share of the NPV represents the expenditures for electricity consumption from the national grid and are not to be confused with the upfront investment costs of the backup systems.

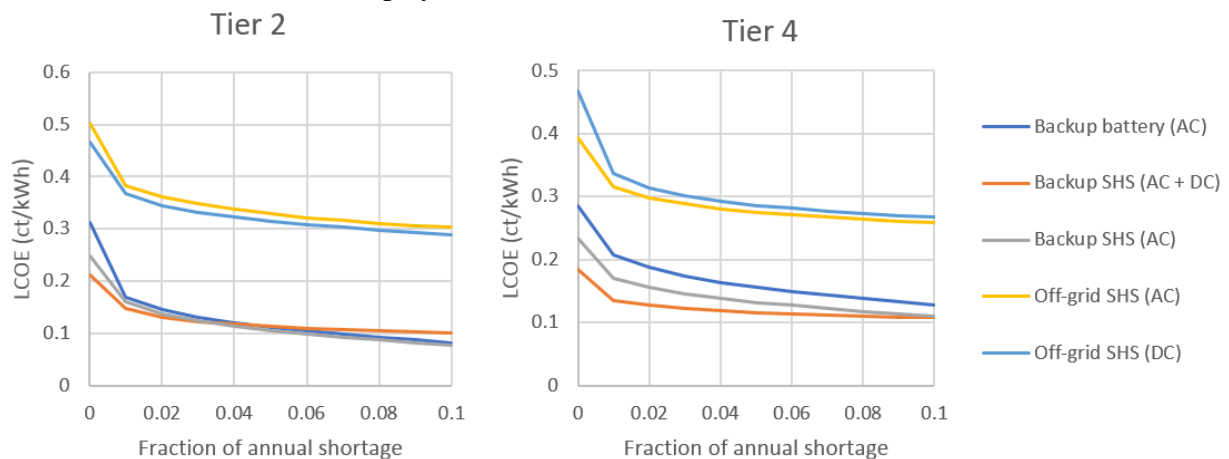


Figure 5. Sensitivity analysis of system optimization and performance depending on allowed shortage

Discussion and conclusion

This study presented and evaluated the potential of multiple supply configurations, with special focus on solar home systems (SHS), to meet the reliability issues of the Nepalese national grid in the municipality of Gauriganj. We used real-time grid reliability measurements to emulate blackout occurrences and survey data to define the two

representative household electricity demand profiles. According to the used appliances and the energy consumption, these two households can be categorized as Tier 2 and Tier 4 consumers according to the multi-tier framework of electrification. The demand profiles were used to evaluate possible backup supply scenarios improving grid supply reliability.

While the status-quo sole national grid supply may be by far the cheapest option for electricity supply in terms of LCOE, it does not provide reliable supply for rural households. Off-grid SHS cannot compete on cost because the electricity from the grid is cheap and the analysis does not consider the capital cost of grid extension. To reach a higher supply reliability, it is necessary to install backup systems aiding consumers to bridge blackout times. Installing a backup battery helps to ensure reliability but is more expensive in terms of LCOE and NPV than the SHS as a backup-system which is the cheapest supply option with 100% reliability. A reliable AC supply for a Tier 2 consumer can be realized for 24.8 ct/kWh (31.1 NPR/kWh) with a SHS of 70 Wp PV and 215 Wh battery capacity. A Tier 4 consumer should install 289 Wp PV panels and a 2 kWh battery, resulting in an LCOE of 23.4 ct/kWh (29.2 NPR/kWh). Agreeing to use DC appliances during blackout times can reduce these costs further to 21.1 ct/kWh (26.3 NPR/kWh) for Tier 2 and 18.4 ct/kWh (23 NPR/kWh) for Tier 4. Further research is necessary to assess the needed additional investment costs connected to the secondary DC circuit in greater detail and confirm the availability of DC appliances in local markets.

In conclusion, we found suitable bottom-up approaches to close the reliability gap of the central system via SHS or back-up batteries. Still, compared to the electricity tariff of the national grid, the costs for reliable supply with decentralized renewable technologies might outweigh the perceived benefit for some consumers. Local awareness campaigns and financing schemes for SHS could increase the adoption rates, reducing barriers hindering consumers from self-reliantly improving their supply and at the same time strengthening the local renewable energy sector. This will most certainly require the support of policies incentivizing investment in decentralized renewable energy supply. Examples from neighboring Bangladesh include the development of technical standards and quality requirements linked to results-based-finance for technology providers.

The challenge of weak grid supply is common across many developing economies. While our study focusses on a specific municipality in rural Nepal, it highlights the potential for decentralized renewable energy supply as a complementary solution to the central grid-based supply in other country contexts with similar challenges. Encouraging bottom-up investment in decentralized renewable energy technologies to satisfy growing energy demand is linked to development outcomes beyond SDG7 [28][29]. For example, the development of a renewable energy private sector can bring investment and employment into rural areas and increase the local accountability of public utilities by providing the population with a viable alternative. Furthermore, although we do not consider rural enterprise energy needs, the motivation and direct economic returns of improving supply for enterprises using decentralized renewable energy supply technologies may well outweigh those for rural households. Reliable electricity supply is crucial for many businesses which would often use expensive and polluting back-up generators. This can be leap-frogged by directly applying batteries or SHS. Moving beyond the on/off-grid dichotomy is necessary to take advantage of technological advances and deliver added value complimenting governmental electrification plans. Our contribution describes a first techno-economic analysis of integrating SHS to reach higher tiers of electrification and close in on SDG7 faster than waiting on national grid extension or improvement of the central power generation capacities alone.

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Appendix

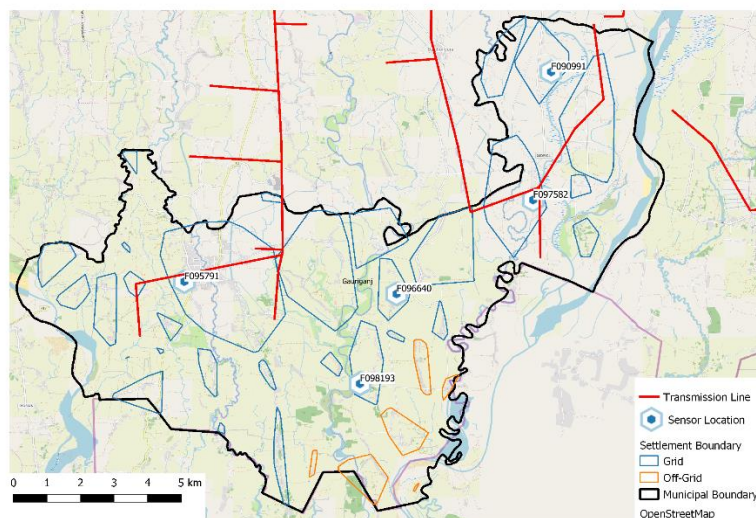


Figure A1. ESMI sensor locations, in Gauriganj municipality, far eastern Nepal. (Source: Authors)

Table A1. Appliance Quantity and Power Rating Definition.

Quantity based on [15][16][18][19] and power ratings based on [5] [20][21][22][23][24][25].

Appliance Type	Ownership	Power Rating (W)		Appliance Quantity	
		DC	AC	Tier 2 HH	Tier 4 HH
LED Room Lighting	97 %	2	6	4	8
Fan	91 %	15	40	1	2
TV	80 %	12	40	1	1
Smart Phone / Tablet	59 %	4	12	1	2
Mobile Phone	55 %	3	5	2	3
Water Pump	27 %	450	500	0	1
Rice Cooker	21%	200	400	0	1
Fridge	19%	20	50	0	1

Table A2. System component costs, according to [26] and market study.

Component	unit	Investment costs (€/unit)	O&M costs (€/unit)	Lifetime
Inverter (DC/AC)	kW	400	50	15
Rectifier (AC/DC)	kW	150	5	15
Storage	kWh	230	15	5
PV	kWp	650	8	20

Table A3. Technical input parameters.

Efficiencies and storage parameters defining oemof components.

PV parameters used to generate specific generation profile from [27].

Efficiencies	
Inverter (DC/AC)	0.98
Connection to national grid	0.95
Rectifier (AC/DC)	0.8
Storage	
Crate	0.20
Efficiency	0.8
DOD	0.7
Max charge	0.95
PV system	
Azimuth	180
Tilt	29°
Location	26.447, 87.7267
System loss	5.00 %

Maximizing the penetration levels of hybrid renewable energy systems in rural areas with demand side management approaches in achieving SDGs

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Abstracts

Access to quality healthcare services is an integral part of sustainable development goals (SDGs) and reliable electricity access is a pre-requisite for improving human lives, enhancing healthcare delivery, education as well as other developmental growth within local communities. However, many rural locations far away from the grid centres have difficulties in accessing electricity, due to distance and cost of extension of grid to such areas, and this has resulted in the inability to provide basic amenities. Rural healthcare centres located in such places are unable to deliver their intended mandate, thus hindering the realization of SDG 3. Therefore, the innovative idea of this study is increasing the penetration of renewable energy technology while minimizing the cost by integrating the users' perspective with demand side management (DSM) approaches, techno-economic analysis, and environmental impact assessment of hybrid energy system configuration, taking a health institution as the case study. To meet the considered rural healthcare facility's initial average load demand of 20.58kWh/day, an optimum PV-Gen-battery hybrid system was selected using HOMER with cost of energy (COE) of \$0.224/kWh, net present cost (NPC) of \$61,917.6 and initial capital cost of \$16,046.5. After the DSM measures were applied to reduce the peak and average demand, an optimum hybrid system was obtained, producing a COE of \$0.166/kWh, NPC of \$18,614.7 and initial capital cost of \$10,070.8. The cost saving realized for the considered rural healthcare facility is \$0.057/kWh, representing a 25.8% reduction from the current COE and a 70% reduction in Total NPC. On the other hand, the optimal configurations gave around a 75% reduction in CO₂ emissions compare to a diesel-alone configuration. The work provides novel insights which may be applicable worldwide. It has the potential to significantly advance the development of high-quality and timely evidence to underpin current and future developments in the rural energy sector and contribute to the implementation of SDG3 and 7.

Keywords: Sustainable Development Goals, Demand side management, Energy Access, electricity demand, healthcare services, renewable energy, reliable supply,

1. Introduction

Reliable electricity access is a pre-requisite for improving human lives, enhancing healthcare delivery, providing education as well as other developmental growth within local communities. However, it has been reported that many rural locations far away from the grid centre have difficulties in accessing electricity, due to distance and cost of extending grid to such area, and this has resulted in the inability of rural healthcare facilities located in such places to deliver their intended mandate [1]. Furthermore, based on the survey data from the report; one (1) out of every four (4) remote healthcare centres in sub-Saharan African countries lack access to electricity, and where the electricity is available, the unreliability of grid supply is characteristic. This deficiency implies that medical equipment such as; ultrasound, autoclave, centrifuge and other portable medical equipment cannot be used in such places because of limited or unstable electricity access to power basic services, hence making operators of these rural healthcare facilities have reduced care capabilities potentially resulting in higher mortality rates. Air temperature is crucial in healthcare facilities, as patients require warmer air due to lower metabolic rates caused by physical inactivity [2]. Hot water is also required for sterilization, laundry, cleaning, washing purposes. These deficiencies have often led to poor quality of health in the rural communities and resulted in many other problems; including obstetric complications, which is one of the root causes of the high maternal mortality rates in the rural areas. Further, the lack of antenatal care, absences of skilled birth attendants and limited availability of emergency obstetrics procedures due to lack of electricity are other reasons for this situation [3].

In many of these remote locations, the traditional approach to providing electricity access should have been extension of central grid. However, the provision of electricity to the rural communities has not improved due to non-access to the grid, coupled with grid unreliability; other constraints include inaccessible terrain, and the high cost of grid extension to the communities. Power generation in rural villages through the use of diesel generators may seem reliable option, if there is proper operation and regular maintenance [4]. However, the noise and environmental pollution resulting from the emission of CO₂ and other harmful gasses could have negative effects on the environment, thus pose a serious drawback [5].

Given the fact that improvement of rural accessibility to electricity via connection to the national grid in many rural locations in sub-Sahara African countries seems impracticable at the moment, and the use of diesel generators is not sustainable, the establishment of a system that is autonomous and off-grid in such locations becomes imperative. In fact, the International Energy Agency predicts that achieving universal electricity access within the 2030 target timeframe of SE4ALL and SDG7 will require 60% of new connections to be delivered via off-grid, renewable-based solutions, with the remaining 40% delivered via main grid extension [6]. Therefore, a solution based on renewable energy (RE) technologies, would be a viable option due to the availability of the certain resources, coupled with the associated environmental friendliness, cost effectiveness in operation as well as sustainability. In the case of rural health facilities, the provision of portable hybrid renewable power supply will enable certain medical equipment, critical lighting and mobile communication devices to be powered in an off-grid area for timely delivery of critical medical care for the rural dwellers.

2. Literature Review

To achieve this, there is need for analysis of various renewable energy configuration options to deliver the most cost efficient and environment benefit choices. Solar, wind, small hydro and biomass make up the different renewable resources in many developing countries, especially in Nigeria. These sources have been assessed in order to establish their potential and viability for electricity generation in the country [7]. Out of the various renewable energy resources in the country, wind and solar are the most favored for electricity generation. However, the investigation of wind power potential at different location in the country shows viable wind speeds are not evenly distributed, as such wind energy is not applicable at all locations in the country. Conversely, solar irradiation data indicates suitable solar energy potentials at almost every location within the country [8]. Moreover, photovoltaic (PV) modules which convert solar energy into electricity also have the advantage of being more suitable for residential buildings on small scale because of its modular structure, zero operating noise, ease of maintenance as well as the environmental friendliness [9].

The potential for solar energy utilization for various activities in the country have been established by different authors in various studies [3], [10-14]. Some of these areas of applications have been identified include; agricultural, industrial, building (commercial and residential), operating pumping machines for water supply and purification, rural electrification, and heating applications [10]. A feasibility assessment of solar energy utilization for electricity generation in buildings has been conducted in Nigeria [13]. A hypothetical remotely located off-grid base transceiver station sites at different geographical regions in Nigeria for solar PV application has been considered [14]. Another key area of application of solar and other renewable sources is in rural health clinics [15]. The optimal configurations of hybrid renewable systems for rural health clinic application in three grid-independent rural villages in Nigeria have also been assessed [3].

However, the major drawback of the utilization of solar PV system is its affordability, due to high initial cost of purchase and installation since there is no obvious or popular national policy that encourages increased renewable energy penetration in Nigeria at present [9].

Government intervention in the form of subsidy on the importation of Renewable Energy Technologies (RET), especially solar PV to bring down high costs, and encourages private individuals and groups to invest in solar technologies would help tap this potential in the country [16]. Therefore, the aim of the innovative idea of this study is increasing the penetration of RET (Solar PV in a hybrid system). The objectives are to model the power requirements of a rural health clinic and how these can be met using solar energy, minimize costs by integrating the users' perspective with demand side management (DSM) approaches, and perform techno-economic analysis, and environmental impact assessment of the hybrid energy system configuration.

3. Material and Methods

3.1 Case study description

A rural health clinic in Nasarawa State, Nigeria having similar characteristics of many rural healthcare centres in Nigeria and other sub-Sahara Africa countries has been considered as a case study. The coordinates of Karu Local Government Area is latitude 9° 08'N and longitude 7° 51'E; and covers an approximate land area of 704 sq. km. The rural community has two distinct seasons (wet and dry), typical of north-central Nigeria.

The health centre consists of two blocks of building housing a consulting room, injection room, card room, a pharmacy, male ward, female ward, a delivery room, and a laboratory. The entire community is off-grid. Therefore, the clinic depends on two gasoline generators for its power supply. Table 1 present the description of the generators, and their operation and maintenance (O&M) cost. Oral interviews with the facility maintenance personnel, physical inspection and observation of energy consumption pattern were carried out to ascertain the level of electricity availability and consumption in the clinic.

Table 1. Current Power Source for the Clinic

Code	Name	Name Plate Details	Target Load	kWh/Day Supplied	O & M Cost
GEN.1	Tiger (TG 2700) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2KVA	Submersible Pumping Machine	2.2	₦0.86/day ₦0.39/kWh
GEN.2	SANDING (SD 3000) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2.2KVA Maximum Output: 2.5KVA	Lighting, Medical Equipment, T.V, Phone Charging and Refrigeration	3.55	₦0.86k/day ₦0.24/kWh
TOTAL				5.75	₦1.73/day ₦0.64/kWh

To achieve the objective of designing a low-cost hybrid power system that uses a mix of Solar PV, diesel generator and battery power bank that meets the rural healthcare clinic need, the methodology employed is shown Figure 1.

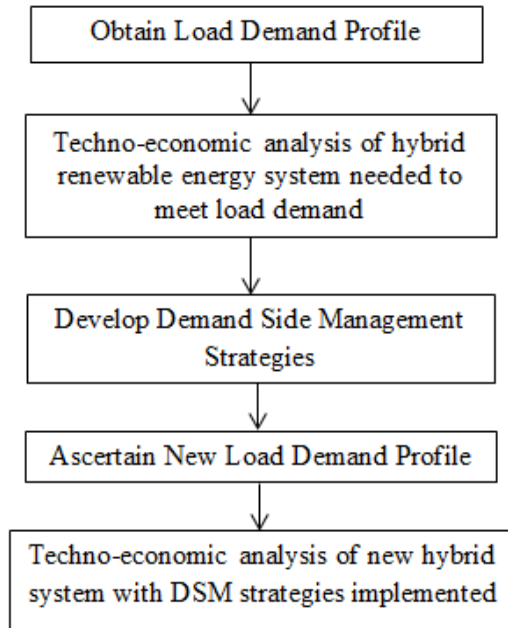


Figure 1. Block Diagram of Methodology

3.2 Current Load Profile at the health centre

The current electricity load profile of the centre supplied by the two generators is shown in Figure 2. The total connected load is 3.2kW, with peak load of 1.5kW and average daily demand of 4.75kWh/day. As observed from figure 2, electricity consumption is shifted towards evening hours when the generators are used mainly for lighting purpose. Other uses of power were shifted to the same hours except during emergency situations. Immunization in the clinic is usually carried out once a month due to lack of power supply to maintain cold chain for vaccines. The lack of an electric centrifuge also slows the process of laboratory tests, as blood samples separation are done manually. The laboratory technician manually operates the microscope in the daytime as there is no power supply required. The lack of reliable power supply has hindered the clinic from providing effective healthcare services to the dwellers.

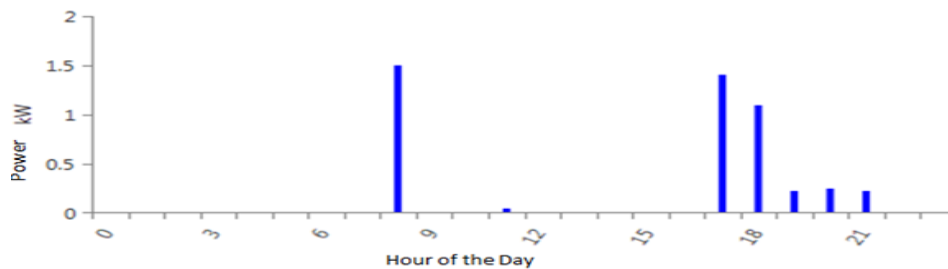


Figure 2. Current Load Profile of the Clinic

However, in order to enhance the service delivery of the health centre, there is need for increasing the number of hours electricity is supplied to the centre. The energy load requirements to allow appliances at the clinic to be fully utilized is shown in Table 2. This new load serves as the input to the optimization software, HOMER with day-to-day and hourly variability of 5% and 10% respectively, to avoid underestimating the peak load.

Table 2. A new load description with all the basic medical appliances functioning

Application	Detail	Quantity	Capacity (watts)	Run time (hours/day)	Peak load(W)
Lighting	Bulb (Incand.)	2	100	12	200
	Bulb(Fluorc.)	10	40	8	160
	Bulb (CFL)	15	18	12	270

	Bulb (CFL)	17	11	8	187
Ventilation	Ceiling fan	8	75	8	600
Medical Equipment	Sterilizer	1	1,500	1	1500
	Microscope	1	20	1	20
ICT and Audio Visual	LCD T.V	1	45	1	45
	Mobile Phones	5	3.68	2	18.4
Water Supply	Submersible Pump	1	1,100	1	1100
Other	Refrigerator(Non-Med)	1	300	1	300

Figure 3 shows the new load profile with 4.64kW connected load, 2.67kW peak load, and 20.58kWh/day average daily demand.

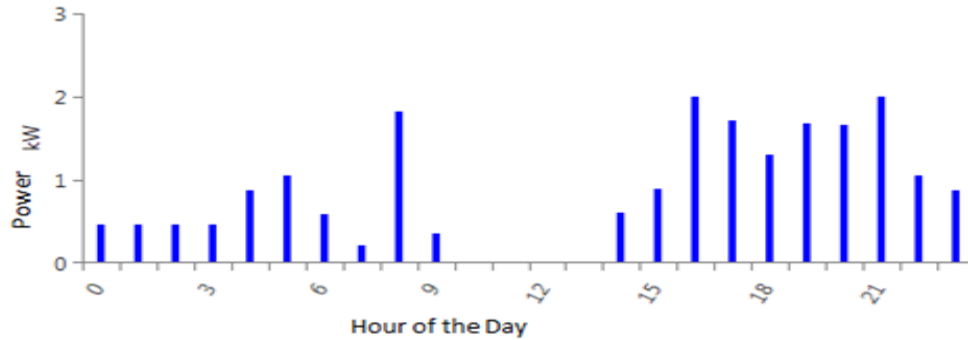


Figure 3. Proposed Clinic Load Profile without DSM

3.3 Hybrid energy system optimal sizing

Hybrid Optimization of Multiple Electric Renewables (HOMER) software designed by US’s National Renewable Energy Laboratory (NREL) was used to design and optimally size the hybrid power supply that meets the clinic load demand. It is an optimization model for micro-power [17]. The inbuilt algorithm HOMER uses for its optimization and sensitivity analysis allows the user to gauge the technical and economic possibility of a variety of electricity generation technology options that can serve a particular load. Different types of data are required by HOMER for simulation and optimization. These include energy resources meteorological data, load profile, equipment characteristics, search-space, economic and technical data.

3.3.1 Resources Data

The monthly average daily solar irradiance data used for the study site is presented in Table 3. These data were obtained from Nigeria Meteorological Agency (NiMET).

Table 3. Monthly average global solar radiation and clearness index for the study site

Month	Solar Insolation	Clearness Index
Jan	5.88	0.65
Feb	6.09	0.63
Mar	6.27	0.61
Apr	6.06	0.58
May	5.58	0.54
Jun	5.06	0.49
Jul	4.42	0.43
Aug	4.18	0.40
Sep	4.73	0.46
Oct	5.30	0.54
Nov	5.97	0.66
Dec	5.87	0.67
Annual	5.45	0.56

3.3.2 System components data

The information regarding components pricing and sizing as adopted in the proposed hybrid system, are presented in Table 4. Present market values were used for the prices of each component per kW [18].

3.4 Demand Side Management

Demand side management (DSM) is a process of managing energy consumption to optimize available and planned resources for power generation [19]. With DSM, it is possible to increase renewable energy penetration, optimize energy costs and reduces carbon emissions. DSM incorporates all activities that influence consumer use of electricity and results in the reduction of the electricity demand. There are two primary indices used in assessing both the economic and technical benefits of DSM. They are the demand side management quality index (DSMQI) for measuring the technical effects, and the demand side management appreciation index (DSMAI) for weighing economic results. These indices help to appreciate the justification for any adopted DSM program.

3.4.1 DSM Quality Index (DSMQI)

Demand side management quality index (DSMQI) evaluates the technical gains of a particular DSM program [19].

$$DSMQI = \frac{kW_{WODSM}}{kW_{WDSM}} \quad (1)$$

kW_{WDSM} and kW_{WODSM} are the kW rating with and without DSM, respectively. A $DSMQI > 1$ is good; the higher the ratio, the higher the benefit of the DSM program.

3.4.2 DSM Appreciation Index (DSMAI)

Demand side management appreciation index (DSMAI) is an index that reveals the economic benefits of DSM programs DSMAI is expressed as[19]:

$$DSMAI = \frac{CkWh_{WODSM}}{CkWh_{WDSM}} \quad (2)$$

$CkWh_{WDSM}$ and $CkWh_{WODSM}$ are the cost of electricity per kWh with and without DSM, respectively.

Table 4. Economic and Technical Specifications

Component Parameter	Values
PV Module	
Capital Cost (\$/kW):	2,500
Replacement Cost (\$/kW):	2,500
O&M Cost (\$/year):	10
Lifetime (years):	25
De-rating Factor (%):	80
Search Space (kW):	0,1,2,3 & 4
Converter	
Capital Cost (\$/kW):	250
Replacement Cost (\$/kW):	250
O&M Cost (\$/year):	10
Lifetime (years):	15
Efficiency (%):	9
Search Space(kW):	0,1,2,3 & 4
Battery	
Model:	Trojan J200-RE
Rating:	2.71kWh, 226Ah
Capital Cost (\$/Unit):	167
Replacement Cost (\$/Unit):	167
O&M Cost (\$/year):	10
Lifetime (years):	7
Search Space (Unit):	0, 8, 16, 24 & 32
Battery String:	1
Generator	
Type:	Generic Auto-size

Capital Cost (\$/kW):	418
Replacement Cost (\$/kW):	418
O&M Cost (\$/hr):	8
Diesel Price (\$ /liter):	0.54
System/Economic Constraints	
Maximum Capacity Shortage	20%
Minimum Renewable Fraction	55%
*Inflation Rate:	17.26%
*Interest Rate:	14.00%

3.4.3 Proposed Demand Side Strategies

In order to reduce energy consumption of the considered healthcare facility, some DSM strategies were considered based on the energy audit conducted. Smart appliance, energy efficiency programs and load partitioning are considered to achieve consumption reduction, thereby reducing the cost of the hybrid renewable energy system in the rural clinic.

3.4.3.1 Smart appliance

From the list of appliances listed in Table 2, the following appliances were observed to be inefficient and high energy consuming: (i) 2 No. 100W incandescent light bulbs(ii) 10 No. 40W fluorescent tubes fittings and (iii) non-medical refrigerator used for preserving vaccines. Therefore, it is proposed that the incandescent bulbs and fluorescent fitting be changed to Compact Fluorescent Lamps (CFLs). A solar vaccine refrigerator will also reduce energy consumption and improve the healthcare service delivery. To ensure each room in the centre is lighted according to standard, calculations were also done for the number of fixtures required for internal lighting.

3.4.3.2 Energy Efficient Water pumping

To ensure efficient use of water pumping machine, the water requirement of the centre was estimated. According to World Health Organization standard, water required a person, per day is 20 litres [20]. For In-patient (admitted patients) and Out-patient (non-admitted patients), it is 60litres and 5litres respectively. Laboratory water requirement is estimated at 75litres per day. A 20% miscellaneous is added for other use. The healthcare center usually has an average of five (5) staff on duty daily, with a total of seven (7) bed spaces for admitted patients.

3.4.3.3 Load partitioning

Loads in the healthcare centre were classified in order of priority as primary (critical) and deferrable (non-critical). The load classification is shown in Table 5.

Table 5. Classification of loads

Category	Detail	Priority
Lighting	All Light Fixtures	Primary
Ventilation	Ceiling fan	Primary
Medical Equipment	Sterilizer	Deferrable
	Microscope	Primary
ICT and Audio	LCD T.V	Primary
Visual	Mobile Phones	Deferrable
Water Supply	Submersible Pump	Deferrable
Other	Refrigerator (Non-Med)	Primary

Deferrable loads are electrical load that must be met within certain period, but the exact timing is not important. The deferrable loads identified, and their analysis, are as follows:

- (1) *Submersible pump*: The clinic pumps water for two (2) hours daily. The pump has a pumping rate of 2000litres/hr. The water requirement of the centre is 714litres per

day (approximately 1000litres per day). It would take pump 0.5hours to pump the daily water required.

- Peak power (pump rated power) = 1.1kW
- Storage capacity = 2 (hours) × 1.1 (kW) = 2.2kWh
- Average deferrable load = 0.5×1.1=0.55kWh/day

(2) *Medical equipment Sterilization:* It takes between 25 to 30 minutes to complete one sterilization cycle.

- Sterilizer peak power = 1.5kW
- Storage capacity = 1 (hour) × 1.5 (kW) = 1.5kWh
- Average deferrable load = 0.5 × 1.5 = 0.75kWh/day

(3) *Mobile phones charging:* It takes on average 2hours to fully charge a mobile phone. However, to reduce power consumption, 1 hour has been allotted per staff on duty to charge their mobile phones when necessary.

- Peak power = 0.0184kW
- Storage capacity = 0.0184 × 2 = 0.0368kWh
- Average deferrable load = 1×0.0184= 0.0184kWh/day

(4) *De-lamping fixtures:* Some lighting loads that were cut down to reduce energy consumption these include: (i) External lighting: reduced to eight (8) points (4 for each block of building). (ii) Ceiling fan: reduced to four (4) points for entrance/card room, labour recovery ward, male and female wards.

3.4.4 New Load Profile with DSM Implemented

Figure 4 shows the schematic of the new hybrid system designed with DSM strategies in place. The schematic contained the two classes of loads (primary and deferrable). The new primary load profile is shown in Figure 5 with total connected load of 1.15kW, peak load of 1.08kW and a daily average load of 7.01kW/day.

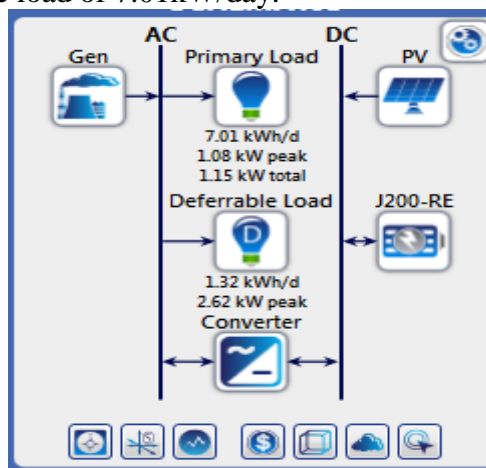


Figure 4. Schematic hybrid energy system with proposed DSM strategies

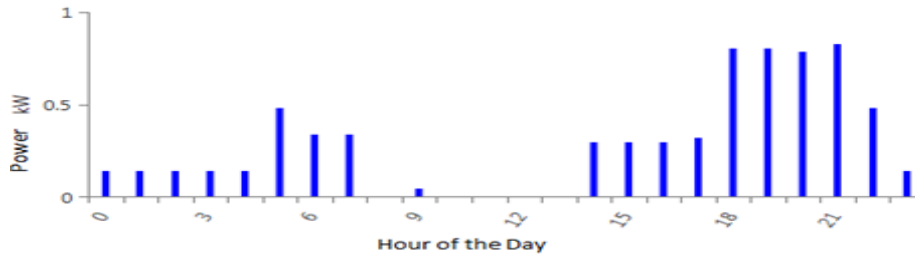


Figure 5. Primary load profile with proposed DSM strategies

4. Results and Discussion

The details optimization results for the selected hybrid system configuration for the considered primary healthcare centre are presented in this section. Input variables were introduced into HOMER to carry out the optimization and give the feasible and optimum system configuration. Results are displayed in categorized form showing the most feasible power system architecture which meets the load and the input constraints.

4.1 Optimization before DSM Strategies

With the load profile shown in Figure 3 and system constraints (Table 4), an optimum hybrid system configuration was obtained for the centre. The optimization result for various system configurations are shown in Table 6. Based on the total net present cost (NPC), the optimum configuration is found to be PV/Gen/Battery system. The configuration consists of a 4kW PV 3kW generator, 24 units (12V) batteries and a 3kW converter. The total NPC and cost of energy (COE) is presented in Table 6. Meeting the facility’s energy need with generator alone will cost \$1,253.6 as initial capital but a total lifetime cost (NPC) of \$114,940 as presented in Table 6. It is worth noting that a PV-Battery system is not feasible with a 20% maximum annual capacity shortage constraint indicated in Table 4. The PV-Battery configuration is only feasible when the maximum annual capacity shortage is increased to 34%.

4.2 Optimization for Hybrid System with proposed DSM Strategies

The result of the optimization for the power system that meet the centre energy needs, with proposed DSM strategies is shown in Table 7. The optimization result shows that with DSM strategies in place, the optimum configuration to meet the electrical energy need of the healthcare centre is also a PV/Gen/battery system, but with 3kW PV, 1.7kW generator, 8 units 12V batteries and a 1kW converter. The Total net present cost (NPC) is \$18,614.7 while cost of energy (COE) is \$0.166/kWh. Meeting the facility’s energy needs with generator alone system after implementing DSM strategies will costs \$710.30 as initial capital and a total lifetime cost (NPC) of \$57.972.90.

Table 6. Optimization result for hybrid power system before DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE (\$/kWh)	NPC (\$)	Capital Cost (\$)
PV-DG-Bat	4	3	24	3	0.224	61,917.60	16,046.50
DG-Bat	-	3	8	1	0.310	85,687.30	2,841.60
Gen. Only	-	3	-	-	0.415	114,940.30	1,253.60
*PV-Bat	4	-	32	3	0.266	70,501.60	18,046.50

*Maximum Capacity Shortage =34% (Not feasible for Maximum Capacity Shortage < 34%)

Table 7. Optimization result for hybrid power system after DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE (\$/kWh)	NPC (\$)	Capital Cost (\$)
PV-Gen-Bat	3	1.7	8	2	0.166	18,614.70	10,070.80

PV-Bat	4	-	16	2	0.202	22,628.90	13,204.90
Gen-Bat	-	1.7	8	2	0.364	40,629.30	2,549.10
Gen. Only	-	1.7	-	-	0.518	57,972.90	710.30

- 4.2.1 *Initial Capital Cost comparison:* The initial cost of the optimum system configuration before DSM is \$16,046.5 as compared to \$10,070.8 after DSM as shown in Table 6 and 7, representing 37.3% reduction in cost.
- 4.2.2 *Total NPC comparison:* For the optimum configuration before applying DSM measures, the total net present cost is \$61,917.6, while the NPC for optimum system configuration with DSM measures is \$18,614.7, representing a percentage reduction of 70%.
- 4.2.3 *Cost of Energy (COE) comparison:* The Cost of Energy (COE), measured in \$/kWh, is a convenient metric to measure the cost effective of the systems, even though HOMER does not rank systems based on COE. Table 6 and 7 compares the cost of energy in both load scenarios, representing 25.8% reduction
- 4.2.4 *Environmental Friendliness comparison:* The optimization results shows optimum system configurations after implementation of DSM measures are more environmentally-friendly, with lower CO₂ emissions than without DSM measure representing 96.6 % reduction as presented in Table 8. In both load scenarios, generator only systems also give the highest CO₂ emissions when compared with other system configuration.

Table 8. Comparison of emission for optimum system configuration after and before DSM strategies

Quantity	Before DSM (kg/year)	After DSM (kg/year)
Carbon Dioxide	2,579	88.22
Carbon Monoxide	10.05	0.56
Unburned Hydrocarbons	0.50	0.02
Particulate Matter	0.05	0.00
Sulfur Dioxide	0.80	0.22
Nitrogen Oxide	1.05	0.52

4.3 Evaluation of DSM Measures

The DSM strategies applied was tested using two indices- the Demand Side Management Quality Index (DSMQI) which give the value of 1.23 and the Demand Side Management Appreciation Index (DSMAI), which gives 1.35 based on computation with equations (1) and (2) respectively. It can be observed that both DSMQI and DSMAI are above one (1), which is desirable to show that the DSM measures applied were productive in reducing connected load and the cost per kWh of electricity. DSMQI is only a little bit above 1, because the connected load after DSM is almost the same except for the load reduction measures in de-lamping external lighting points and taking out some ceiling fan loads. DSMAI on the other hand is little bit higher because of the demand response measures applied, leading to load partitioning namely primary and deferrable.

5. Conclusions

The study identified the lack of modern electricity supply as a major impediment to proper functioning of the healthcare centres in the rural areas thereby hindering effective realization of SDG3. The study has been able to model a PV hybrid microgrid to meet the energy needs of a rural health clinic. It has shown that DSM strategies are an effective means to reduce capital and operation costs through economic analysis. Furthermore, the environmental

impacts of providing power are also reduced through cuts in air pollution. This work provides novel insights into renewable energy penetration which may be applicable worldwide. It has the potential to significantly advance the development of high-quality and timely evidence to underpin current and future developments in the rural energy sector and contribute to the implementation of SDG7.

An energy audit was conducted at a case study rural clinic located in Nigeria with the aim of proposing DSM measures to increase renewable energy penetration at the healthcare centre. The baseline load profile generated showed power supply shortages at the healthcare clinic. To improve healthcare service delivery, a new load profile was designed to meet the expected energy need. This resulted in peak load, total connected load and average daily demand of 2.67kW, 4.64kW and 20.58kWh/day respectively. The optimum system to meet the present load was found to be PV/Gen/Battery system with NPC of \$61,917.6. The COE, initial capital cost and CO₂ emissions of the system were \$0.224/kWh, \$16,046 and 2,579kg/year respectively.

To reduce both NPC and initial capital cost, DSM measures were proposed. The DSM measures including de-lamping external lighting fixtures, reduction of ceiling fan points and load partitioning into primary and deferrable loads. With the proposed DSM, the new load profile was simulated with the required energy resource. The optimum system configuration was also found to be PV/Gen/Battery system, but with reduced initial capital cost of \$10,070.8, NPC of \$18,614.7, total COE of \$0.166/kWh and a renewable fraction of 98%. With DSM strategies implemented at the healthcare centre, a cost savings of \$0.06kWh was achieved, representing a 25.8% cost reduction from the present cost of energy per kWh, and 70% reduction in the total net present cost. The optimum system also has around a 96% reduction in CO₂ emissions.

The impact of this study is shown in the fact that SDG 7 (affordable and clean energy) offers a series of interlinkages with other goals, such as SDG13 (reduce GHG emission) and SDG3 (access to quality healthcare services). Thus, it is expected that the results of the analysis in the study will be useful for planning stand-alone or mini-grid energy generation systems for off-grid remote healthcare centres locations around the world for effective realization of SDG3.

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Policy coherence to enable effective energy strategies and promote sustainable development: toward developing an integrated simulation model for Nigeria

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Abstract

The SDGs were promoted as a set of “integrated and indivisible” goals based its inclusion of the economic, social and environmental dimensions of sustainable development. Since coming into force, there has being continuous effort towards establishing the inter-linkages between the goals and targets. In this context, energy sector has been widely acknowledged as pivotal to achieve the SDGs. As a contribution towards the integration of the SDGs and to demonstrate the enabling role of energy access within the SDG framework, we built on the system dynamics-based simplified integrated Sustainable Development Goals (iSDG) model to facilitate the formulation, analysis and critical evaluation of various energy policies and plausible impact on sustainable development in Nigeria. The model is still work in progress, but it is expected to facilitate the formulation of appropriate energy policies, resource allocation of energy intervention funds, and budgetary allocations in determining optimum energy mix and high leverage complementary actions that can promote the effectiveness of energy access programmes and strategies.

Keywords: energy access, SDGs, system dynamics, sustainable development goals, policy coherence

Introduction

The pivotal role energy access (SDG 7) in meeting the Sustainable Development Goals (SDGs) is promoted in the Agenda 2030 set by the United Nations in 2015 [1], largely contributes to increasing support for the implementation of sustainable energy projects worldwide, especially in developing economies [2], [3]. Several authors have established the linkages between the SDG 7 and the other SDGs, mostly at qualitative level. Assessing the nexus between the energy sector and the other SDGs is indeed not straight-forward, because it involves “complex” systems, whose interactions give rise to unexpected behaviours that are far from being completely characterised and understood.

The lack of the understanding of the complexity of energy-development nexus when designing, planning, and allocating monetary resources in energy policies and energisation programmes in developing countries, often leads to the assumption that energy access will “automatically” push socio-economic development [4]. This can result into simplistic models and relations, leading to optimistic but unrealistic projections, and consequently to inefficient, ineffective, and sub-optimal energy policies. This inherent complexity of the energy-development nexus can explains why some past energy programmes and policies have been successful in some developing countries, while others have experienced only a limited impact on sustainable development. This heterogeneity in terms of impact results call for adequate resources planning, and energy policies that are able to take into account the multifaceted complexities and dimensions of sustainable development. In this framework, given the presence of multiple interconnected systems, time-dependencies, uncertainties, and non-linear behaviours, a system thinking approach supported by simulation-based tools is advised.

In this framework, the main goal of this study is to start the development of an integrated model to support the evaluation and design of effective and sustainable energy policies for Nigeria.

Literature review: efforts towards policy coherence and integration of the SDGs

Whereas the SDGs were promoted as politically “integrated” goals, they probably would be best described, technically, as a set of related goals. The 2030 Agenda contains as a set of related but separate list of global challenges prioritised by the United Nations. However, since coming to into force, there has been continuous effort towards establishing the inter-linkages among the various goals and targets which are progressively helping towards the technical integration of the goals.

As an initial effort towards integrating the SDGs, the United Nations Department of Economic and Social Affairs (UN DESA) [5] analysed the structure of the first 16 SDGs to assess the extent to which the structure of the goals, through their targets, align with the sectorial integration objective of the 2030 agenda. Goal 17 which is taken as means of implementation of the SDGs, and, all the 62 targets that refers to it throughout the framework were not included in the study. The network of targets was developed based on a matrix linking each of the considered 107 targets to all the goals their “wordings” may refer (Figure 1).

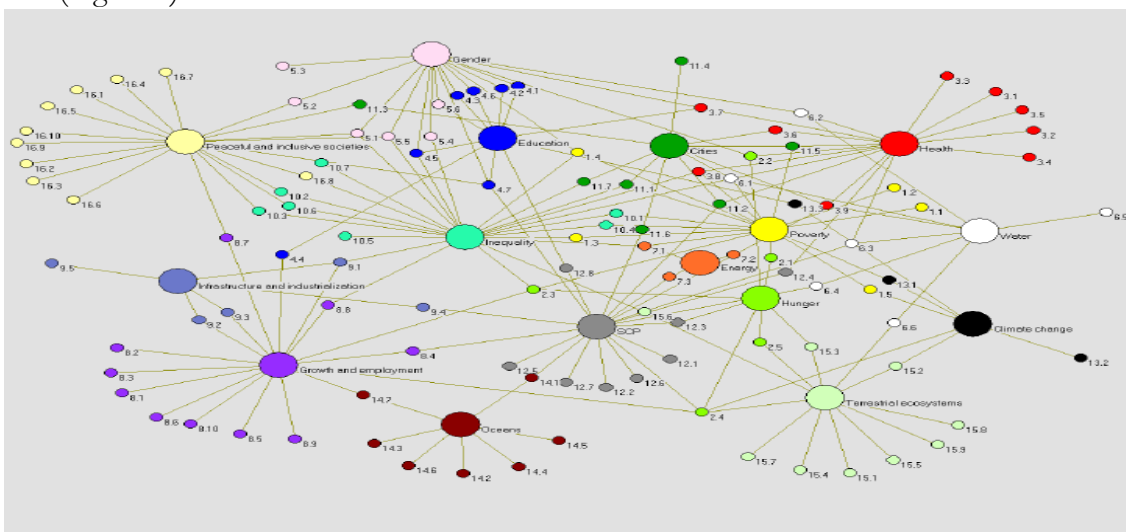


Figure 1: Links between the SDGs through targets
(Source: Blanc 2014)

Being based on the use on the interpretation of *wordings* used in the statement of goals and targets, the authors themselves highlight that the approach has some element of subjectivity as interpretations may differ with researchers. Also, whereas the approach represents a step towards integration of the SDGs, it leaves out systemic linkages between goals that are technically linked but not by means of wording. For instance, no linkages were established between energy (SDG 7) and climate change (SDG 13), and energy (SDG7) and infrastructure and industrialisation (SDG 10) which have been scientifically identified to be closely linked.

In the literature, other efforts have been made by researchers to interlink the SDGs using a three-point typology. They categorised the interactions between the SDGs into *supporting, enabling and relying* [6], [7]. Another attempt to interlink the SDGs is provided by Nilsson [8], which establishes *most crucial* linkages between the targets of six SDGs 1, 2, 3, 5, 9 and 14 (which were selected for review at the 2017 High Level Political Forum), and other SDGs. The interlinks were made through the linkages between selected targets under the six SDGs and the targets of other goals within the framework to highlight the most important interactions between the six SDGs considered in the review and the rest of the SDG framework. The study also considered the institutional implications of the interactions between the SDGs. The assessment of the linkages was based on the seven-point typology developed by Nilsson [8], [9] which categories and assigns values +3 to -3 to the interactions between the SDGs. While the + and - sign shows the direction of the influence, the numbers shows the strength. The typology assigns

values to the linkage between a target "X" to target "Y" depending on whether progress in target "X" is indivisible (+3), reinforcing (+2), enabling (+1), neutral (0), constraining (-1), counteracting (-2) or cancelling (-3) the progress of target "Y". The seven-point typology was applied to establish qualitative relationship between SDG 7 and other 15 SDGs taking SDG 17 as a means of implementation of the SDGs [10].

So far, all the approaches described are still limited to qualitative analyses. Of course, they are helpful for increasing the understanding of stakeholders on the linkages between the SDGs and their targets. However, the progress made can make only limited contributions towards integration and policy coherence of the 2030 Agenda. The approaches used are subjective, and qualitative, thus, insufficient to support policy actions.

In view of supporting national governments in policy design, formulation and assessment, the Millennium Institute (MI) developed a system dynamics-based modelling tool (integrated Sustainable Development Goal - iSDG) which models the non-linear causalities and feedback relationships between the SDGs capturing the time delays involved in their interactions. The iSDG builds on the Threshold21 (T21) model [11], a system dynamics-based model that have been used in development planning for more than 30 years and applied to various developing and developed countries including Malawi, China, Italy and USA. The iSDG model is a system dynamics-based simulation tool for analysing, evaluating and testing of complex systems, and it has been applied in various fields including business operations, logistics, and shipping, among others.

The Millennium Institute's iSDG modelling tool contains over 1000 "stocks/levels" – viz. the system dynamics representations of integrals in mathematical terms – and "flows" – viz. derivatives in mathematics – which are connected through several thousands of feedback loops covering all the 17 SDGs and 78 indicators. Given the size and complexity of the model, the model has been divided into 30 sectors; 10 for each of economic, social and environment main sectors [12]. The uniqueness of iSDG is the way the modelled sectors have been interrelated into a complex system. Each of the sector has its internal mechanism such that they could be considered individually and also connected with other sectors as a complex system. Calibration is performed by way of partial model calibration cycles, also including rounds of multi-parametrical optimization. The model parameters are estimated based on relevant literature and historical calibration for the period 1990-2013/14.

Although geographical disaggregation is not used in iSDG, the main social, economic and environmental variables are broken down in sub-components in order to analyse the focus issues. For example, population is divided into 101 age-cohorts and 2 genders, and the age-gender distinction is used in most social indicators; production is divided into industry, services and agriculture, this last further divided into crops, fishery, animal husbandry and forestry; land is divided into forest, agriculture land, fallow land, urban land and desert land.

The development of the iSDG model tool represent a major improvement in the efforts towards integration of the SDGs and policy coherent for implementation based on the synergies and trade-offs within the SDGs for simultaneous achievement of the SDGs. Using the system dynamic approach, they were able to capture the systemic linkages and causalities including the mathematical relations which provides for quantitative evaluation and analysis for identifying, analysing and evaluating effective integrated policies towards realising the SDGs. The model has been calibrated and applied to support various national government towards aligning their national development (Cote D'Ivoire and Tanzania, for instance) strategies to the SDGs adopted for development planning [12], [13].

Materials and Method

Nigeria has been a target country for various support programmes aimed at improving the Nigerian energy sector. The 200 million US\$ loan from the African Development Bank [14], the Germany-EU funded Nigeria Energy Support Programme, World Bank's 486 million US\$ grant to improve electricity transmission and ESMAP's 150 million US\$ from the World bank for off-grid energy access are few examples. Many of the intervention funds have been dedicated to rural electrification especially through mini-grids with the aim of providing electricity for household and productive use to facilitate

sustainable development in rural communities. In 2013, a private energy company commissioned a 6kW mini-grid project in Nigeria that has been operational and sustained over time [15]. Since then, there has been various mini-grid projects developed across the country mostly powered by solar energy. Whereas the northern Nigeria receive more solar radiation (9.0kWh/m²/day) than the south with the minimum solar radiation of 3.5kWh/m²/day [16], the sustainability of various mini-grid projects developed across the country has proven the technical viability of solar mini-grids in all parts of the country. Up till date, more than 11 mini-grids [17] have been developed in Nigeria to provide energy access in unserved off-grid rural communities with various funding initiatives for energy access in Nigeria. Other funding supports are targeted at supporting the government to strengthen the capacity of the national electricity grid such as the World Bank's USD 486 million grant to Nigeria to improve electricity transmission in the country.

Given the increasing attention of the government, international organisations and development partners, among other stakeholders in improving the Nigerian energy sector, we contribute by starting the development of a model to support the evaluation and design of effective and sustainable energy policies that will ensure efficient and effective resource allocation and use of the available funds. The overall general objective is to support sustainable development in the country by enabling the development of effective energy policies. Given the various evidence from literature on the need for complementary actions to maximise the impact of energy intervention projects [4], the intended use of the model is also to test various resource allocation strategies which consider the use of a share of the available energy funds to support complementary actions in other sectors that are crucial for effectiveness of the impact of energy access.

In this work, we give a snapshot of the modelling endeavour in formulating the complexities between energy and other themes of development, capturing the non-linear relationships, feedback and time delays. This is still a work in progress, which might contribute to the modelling effort of other researchers involved in tackling similar issues in other developing countries.

In the following sections, we describe the model conceptualisation which captures the linkages and causalities between the sectors endogenously integrated in the model. The formulation process transformed the causal loop diagrams into model by integrating the underlying integral, differential and algebraic equations. The model is also partially calibrated using Nigerian data collected from the World Bank.

Model conceptualisation

By relying on a system-thinking approach and building on the system dynamics-based T21 model developed into a simplified iSDG model by the Millennium Institute [18], we improved on the model by integrating the renewable energy sub-sector and by re-calibrating it using Nigerian data collected from the World Bank. The improved model integrates the fundamental variables of ten (10) sectors of the Nigerian economy.

Figure 2 shows the causal loop diagram (CLD) shows how the integration of renewable energy into the energy mix impact energy consumption and the gross domestic product (GDP) as examples of the reinforcing and balancing loops in the model.

The causal loop diagrams provides a pictorial view of the interactions between the variables. The CLD comprises of variables and their causal linkages represented by arrows. The arrows connect independent variables (variables at the tail of the arrow) to the dependent variables at the arrowhead. Each arrow has either a positive (+) or negative (-) sign, which indicates the kind of relationship between the independent and dependent variable. While a *positive (+) sign* represents that a change in the independent variable (at the tail of the arrow) will lead to a change in the *same* direction in the dependent variable (at the arrowhead), a *negative (-) sign* indicates that a change in the independent variable (at the tail of the arrow) will lead to a change in the *opposite* direction in the dependent variable (at the arrowhead). The nature of the feedback in each loop is indicated with a Loop Identifier. A Loop Identifier starting with a loop identifier **R** indicates a Reinforcing Feedback Loop while **B** represent a balancing Loop.

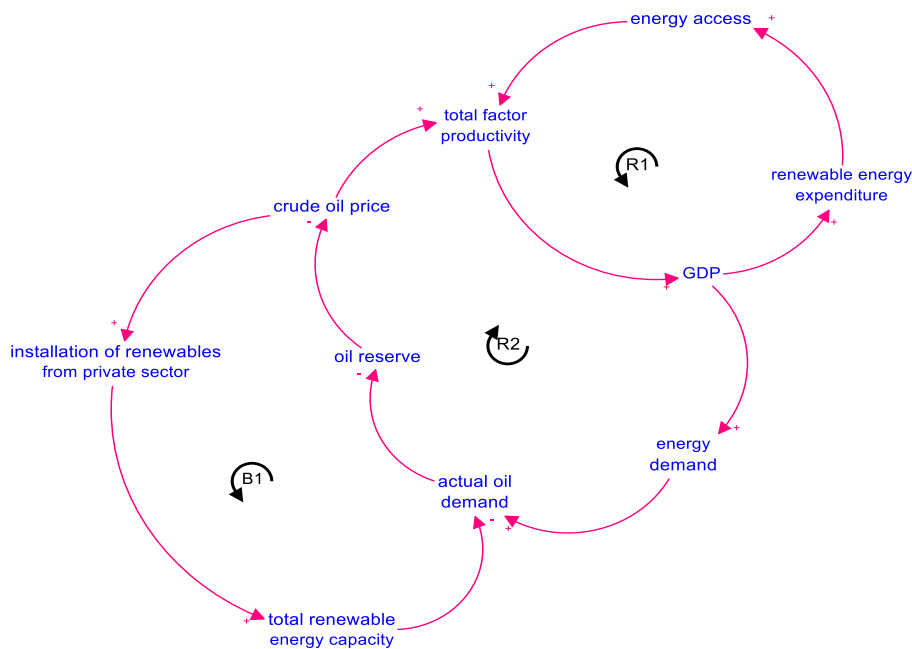


Figure 2: Causal Loop Diagram showing the dynamics of renewable energy, consumption of crude oil and GDP

R1 (Reinforcing loop): $energy\ access \rightarrow total\ factor\ productivity \rightarrow GDP \rightarrow renewable\ energy\ expenditures \rightarrow energy\ access$

Increasing energy access increases the efficiency of combination of factors of production (increasing the productivity of factors of production) thereby increasing GDP which increases the share of resources available for renewable energy investment thus increasing energy access.

R2 (Reinforcing loop): $GDP \rightarrow energy\ demand \rightarrow actual\ oil\ demand \rightarrow oil\ reserves \rightarrow crude\ oil\ price \rightarrow total\ factor\ productivity \rightarrow GDP$

Increase in GDP increases the size of the economy (e.g businesses) which requires more energy hence increase in the demand for crude oil thereby reducing the oil reserves. In accordance to the law of demand, the price of oil increase as the available reserve of oil decreases hence necessitating improvement in technology of production to facilitate increase in productivity, hence, increase in GDP.

B1 (Balancing loop): $Installation\ of\ renewables\ from\ private\ sector \rightarrow total\ renewable\ energy\ capacity \rightarrow actual\ oil\ demand \rightarrow oil\ reserve \rightarrow crude\ oil\ price \rightarrow Installation\ of\ renewables\ from\ private\ sector$

Investment in renewable energy increases the total renewable energy capacity thus reducing the volume of crude oil required for energy generation. The reduction in oil demand reduces the amount of oil exploration (thus increasing the amount of oil in the oil reserve) thus reducing oil price. The reduction in oil price leads to increase the interest in oil for energy production thus reducing renewable energy installation.

The three loops show the causalities between energy access, GDP, Oil reserves, and how renewable energy interventions affect the dynamics. R1 and R2 reflect oil dominated energy sector in Nigeria showing continuous increase in GDP by increasing energy access however, leading to continuous depletion of the oil reserve which is finite in nature, hence unsustainable. The balancing loop B1 explains how the renewable energy intervention could be used to achieve increase in GDP by increasing energy access yet reducing the depletion of oil reserve.

Model formulation

Formulation of system dynamics model describes the process of transforming the causal loop diagrams into *stock* and *flow* diagrams with algebraic, differential and integral equations including the estimation of *parameters* required to specify the mathematical structure of the model. The mathematical structure of

the model is based on the causal loop diagram developed during the conceptualisation phase. While the stocks represent integral equations, the flows are differential equations while all other variables are solved algebraically. Euler's integration method is applied in the model using the Stella Architect software which solves all the equations in the model for every discrete time-step dt specified in the model (Table 1).

Table 1. -Model settings

Time unit	year
Time step Δt	1/16 (=0.0625)
Start time	1990
Final time	2030
Integration method	$Y_{t+\Delta t} = \int_t^{t+\Delta t} x \cdot dt = Y_t + x_t \cdot \Delta t$

The model is formulated to simulate the long-term impact of various renewable energy policies on energy access, crude oil demand, gross domestic product, education, health in Nigeria from 2017 till 2030. As an illustration of the stock and flow diagrams and the underlying equations in the model, Figure 3 shows the dynamics of the oil price, investment in renewable energy and energy access. An example of mathematical formulation is represented below:

$$\int_t \frac{d(\text{total renewable energy capacity}(t))}{\text{installation from private}(t) + \text{installation from public}(t) - \text{depreciation}(t)} = \int_t dt$$

$$\text{installation from private}(t) = \frac{\text{target private investment in renewable energy}(t)}{\text{investment cost per kW}(t)}$$

$$\begin{aligned} \text{annual funding for renewable for new energy access}(t) &= \text{annual funding for renewable}(t) \\ &\quad * \text{share of funding for renewable for energy access}(t) \end{aligned}$$

$$\int_t \frac{d(\text{renewable energy for new energy access}(t))}{[\text{installation of renewable energy for new energy access}(t) - \text{depreciation of renewable energy for new energy access}(t)]} = \int_t dt$$

$$\begin{aligned} \text{total population with energy access}(t) &= \text{initial population with access to energy}(t) \\ &\quad + \text{new people with energy access}(t) \end{aligned}$$

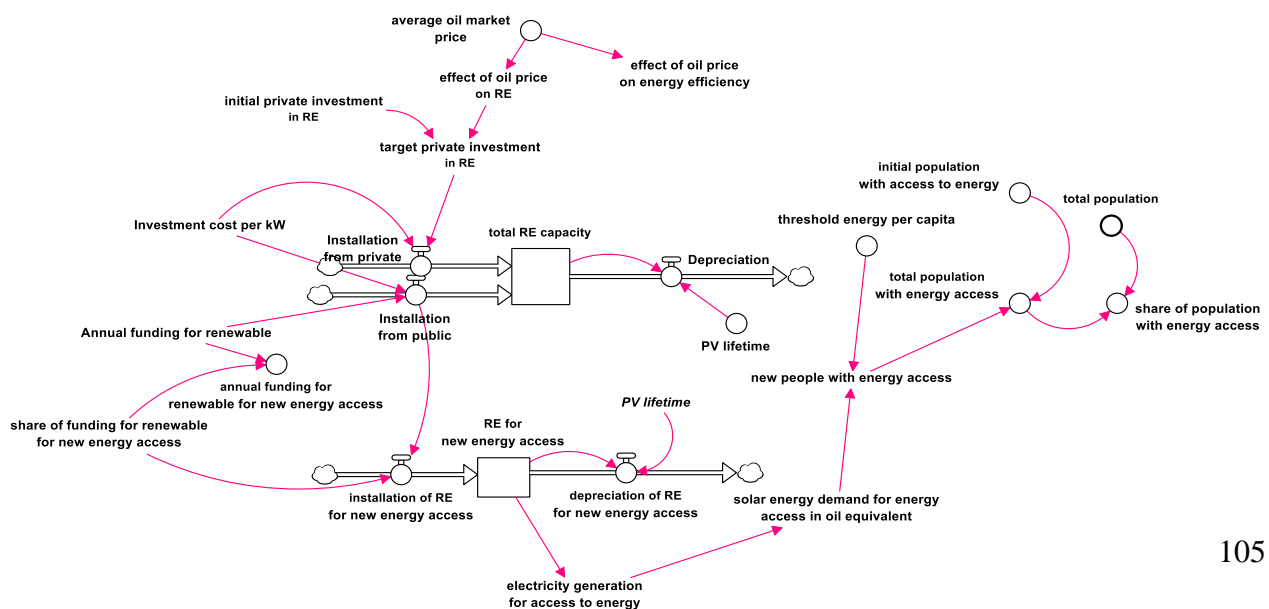


Figure 3: Formulation of the stock-and-flow model for the energy sector

$$\text{share of population with energy access } (t) = \frac{\text{total population with energy access } (t)}{\text{total population } (t)}$$

Figure 4 exemplifies another mathematical structure of the model. It represents the economic dynamics showing how change in various economic input impact the total factor productivity (tfp) and their overall impact on the gross domestic product (gdp). In the field of economics, Production Function is usually employed to express mathematical relation capturing the various factors of production and the technology of production which represents the efficiency of the combination of the factors. Using the Cobb Douglass production function, the output is expressed as a product of the production function and all the inputs with each input raised to the power of its respective elasticity. The elasticity of output Y to input X expresses the degree of responsiveness of the output Y to a unit change in input X. The generic Cobb Douglass function is expressed as:

$$Y = A \prod_{i=1}^n X_i^{\varepsilon_i}$$

Where X_i represents the input i , ε_i is the elasticity of the output Y to input X and A is the total factor productivity (tfp) which captures, in the GDP, the effect of the changes in all the economic inputs based on their respective elasticities.

effect of access to energy on tfp

$$= \left[\frac{\text{total population with energy access}}{\text{initial population with energy access}} \right]^{\text{elasticity of tfp to access to energy}}$$

*tfp = effect of roads density on tfp * effect of life expectancy on tfp * effect of literacy rate * effect of energy price on tfp * effect of access to energy on tfp*

*gdp = tfp * initial gdp * relative capital^{capital elasticity} * relative working age population^{labour elasticity} * relative agriculture land^{land elasticity}*

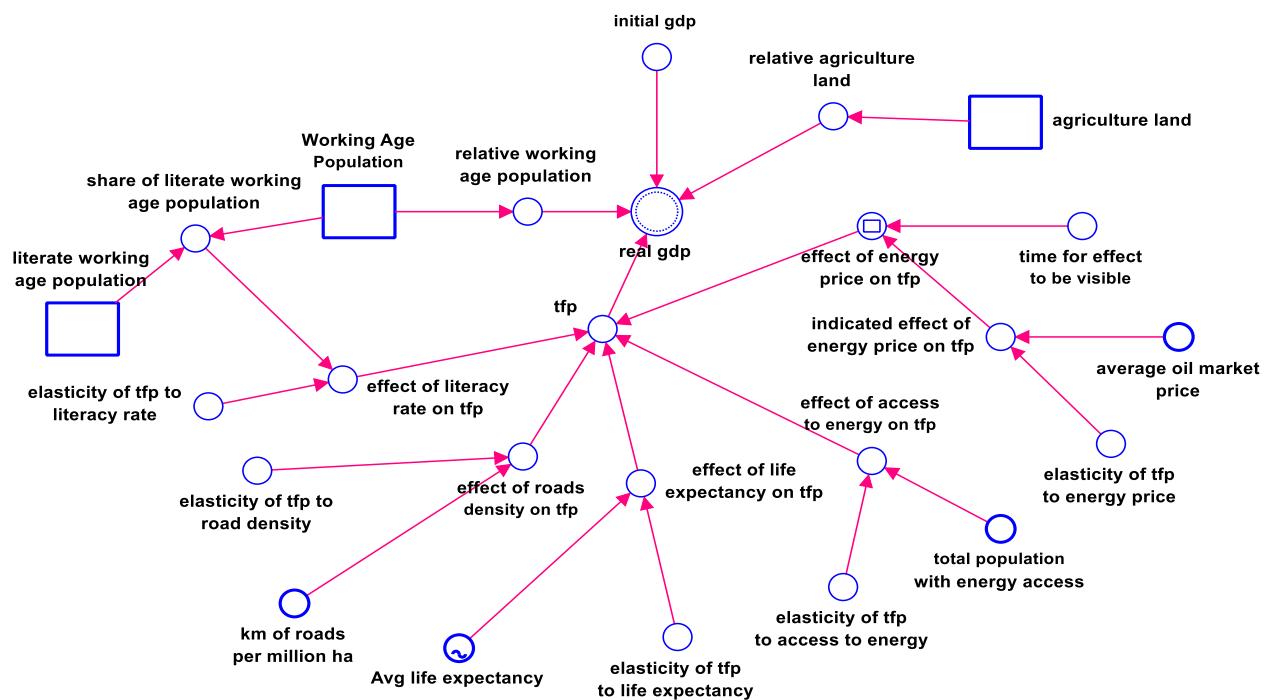
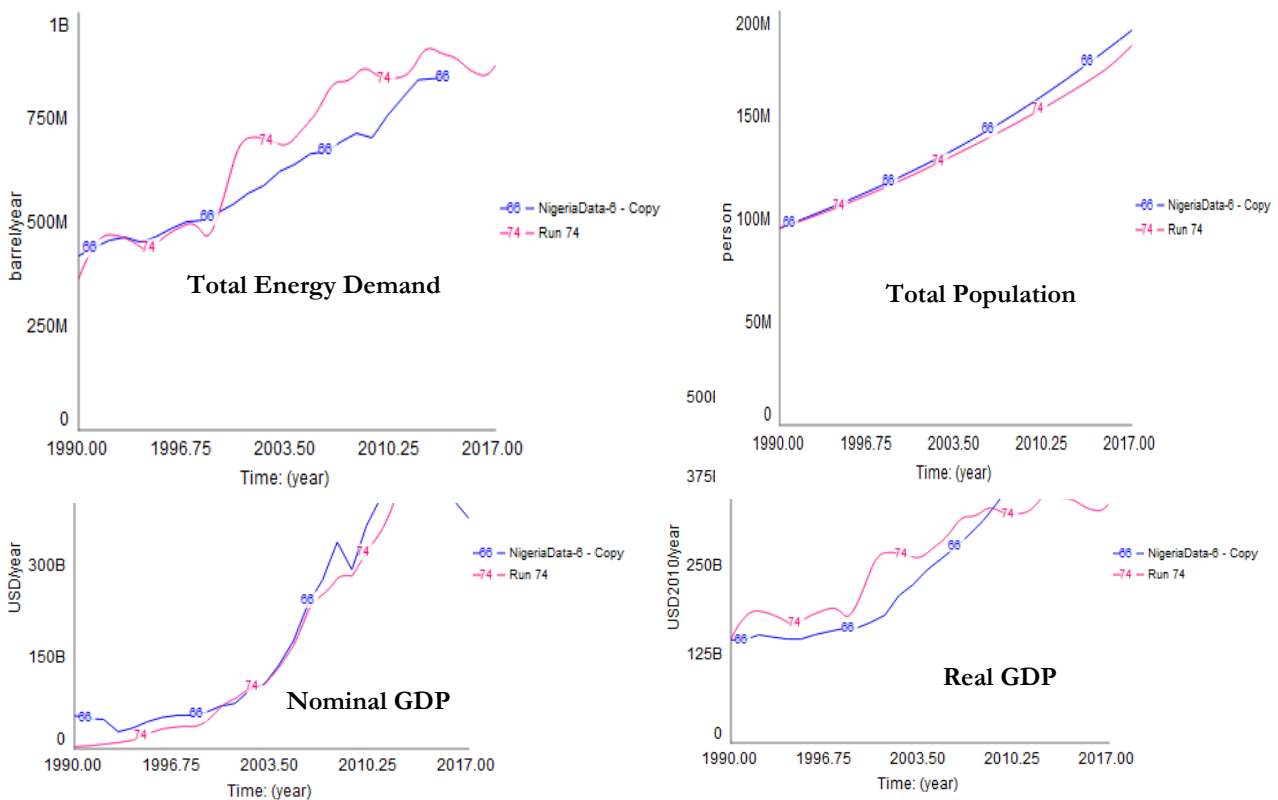


Figure 4: Formulation of the stock-and-flow model for the GDP sector

Model calibration

Models have been said to be abstract of the reality. Model Calibration is an essential phase in the modelling process that modellers use to assess how well the structure of the model is able to replicate historical trend, hence, building confidence in the model in its ability to project into the future. Nigerian data (1990-2015) were sourced from the World Bank and used in calibrating the model while the calibrating the parameters were collected from various sources including the World Bank data. The figures below show some of the results of the calibration process.

While the overall objective of the modelling exercise is to develop a modelling framework that could be used to assess the plausible impact of proposed policies on the energy and other sectors of the Nigerian economy, so far, we have been able to model the interconnectivities between all the sectors considered for the model and calibrated energy, population, GDP, land, with data for Nigeria from the World Bank.



The calibration effort is not concluded, but the preliminary results show a fairly good ability of the model of capturing the observed historical behaviour of the system showed by data. In particular, the model results for nominal GDP and real GDP has some deviation from the data from 2015-2017 and 2010-2017 respectively which suggest that some dynamics that may not have been endogenously captured in the model or some inaccuracies in the data from those years especially the data for nominal GDP which shows a sudden drop from 2015.

Discussion, Conclusion and the Way forward

Whereas this paper is a work in progress, it presents the results of a modelling process that, at the level of work attained, captures the dynamics of the energy sector (fossil fuels, renewables, and access to energy) with ten major sectors of the Nigerian economy. The model results capture the non-linearity of the data which allows us to link different sectors, thus, avoiding “black-box” exogenous relations and

approaches in designing energy policies. Thus far, the model, which is partially calibrated, allows us to increase our knowledge of the energy-development dynamics in the Nigerian context by serving as a holistic and integrated quantitative tool for understanding how energy variables interact and impact the variables of other sectors of the Nigerian economy.

At the completion of the calibration process, the model will be fit to evaluate various scenarios of energy policies such as energy investment, resource allocation of energy intervention fund and budgetary allocations vis-à-vis their respective plausible impact on sustainable development assessed through improvement in for determining, analysing and evaluating optimal energy mix from crude oil and renewables sources and their impact on energy access, GDP, health, education, among other sectors captured by the model. The model will be a tool to evaluate the impact of various scenarios of energy investment, intervention fund and budgetary allocations on household income (SDG 1), education (SDG 3), health (SDG 4), energy access (SDG 7), economic growth (SDG 8) and infrastructure development (SDG 9).

The model will also be a tool to identify necessary complementary actions and their effectiveness in maximising the impact of energy interventions to facilitate sustainable development in Nigeria. Users of the model would be able to compare the impact of various resource allocations including ascertaining what level of investment are required in other sectors for effective impact of energy investment.

Acknowledgements

We would like to thank Dr. Matteo Pedercini for his kind support.

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Poster session



Rural Electrification Strategies to Address Energy Access and Climate Change

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Background

- As of 2017, 840 million people lacked access to electricity [Fig. 1]. Moreover, household access remained unreliable or unaffordable in many countries (WB, 2019).
- SDG 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services.
- IEA's New Policies Scenario (2017) predicts that around 650 million people would still lack access to electricity by 2030 [Fig. 2].

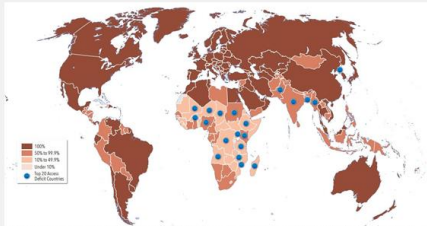


Figure 1: Share of population with access to electricity in 2017 (WB, 2019).

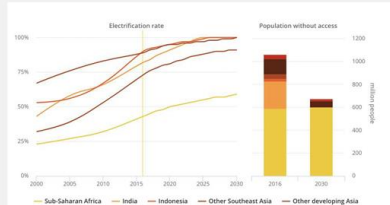


Figure 2: Access to electricity, 2000-2030 (IEA, 2017).

- Technology innovations and cost decreases in solar photovoltaics (PV) and battery storage provide an opportunity to achieve this target.
- Grid extension, minigrids and off-grid systems will be needed [Fig. 3 & 4]. Developing countries have the opportunity to leapfrog to a more decentralised and renewable energy provision.

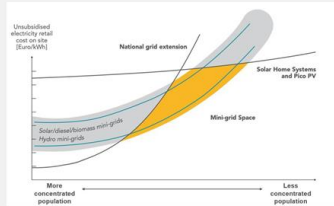


Figure 3: Opportunities for grid-extension, minigrid and distributed renewable energy systems (Adapted from SEforALL, 2019).

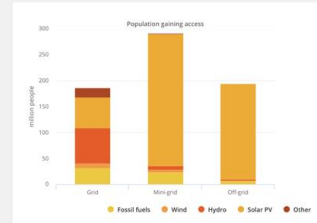


Figure 4: Providing electricity to all by 2030 (IEA, 2017).

Aims & Research

The research will seek to answer the question: What are the comparative costs and environmental impacts of grid extension, minigrids and off-grid systems to reduce energy poverty?

Methods

1. **Case studies** in rural regions of developing countries.
2. **Economic analysis:**
 - a. Understand electricity demand profiles, understand costs of electrification options, and collect data on electricity costs.
 - b. Simulate costs of electricity provision using the **CLOVER** model – a minigrid simulation and optimisation tool.
3. **Environmental analysis:** understand and calculate the environmental impacts of grid-extension, minigrids and off-grid systems.



Source: Sandwell, P. (2017).

More about **CLOVER**: <https://github.com/phil-sandwell/CLOVER>

Next Steps

- Select case studies: Latin America, Sub-Saharan Africa, Southeast Asia.
- Undertake data collection, questionnaires, and expert interviews.
- Calculate economic and environmental implications of different electrification strategies.
- Construct analytical framework to compare electrification pathways.
- Apply to off-grid, minigrids and grid electrification strategies.
- Make policy recommendations.

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Modelling isolated electricity systems and connecting microgrid systems.

RENGA Project: Resilient Electricity Networks for a productive Grid Architecture.

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Project Structure



Benchmark Microgrid Model

- Develop benchmark model for single microgrid in Rwandan context.
 - Based on data on cost, locations, and demand
 - Develop demand profiles for different energy access tiers (1-4)
- Use CLOVER (Continuous Lifetime Optimisation of Variable Electricity Resources) modelling tool to calculate optimal system sizing in benchmark microgrid.
- Develop collaboration with other project partners (JURICE, Tribhuvan University Nepal, BBOCOO) to refine and develop parameters for particular contexts.

Connecting Microgrids

- Consider ways to model multiple interacting microgrids
- Calculate cost/benefit of microgrid interconnection in specific (and/or generalised) scenarios. This could include:
 - Reliability, LCUE, GHG intensity
 - Costs: cables, electronics, (soft costs? e.g. legal, logistics?)
- Dependence on: distance, terrain, coincidence of demand, grid properties (12/24V DC/AC)

Grid Interaction

- Work with other RAs to develop a better representation of grid-microgrid/microgrid-microgrid interactions within CLOVER. This could include:
 - Power quality
 - Range of impacts of reduced power quality (beyond lack of energy & blackout)

Case studies: Microgrids in India and Brazil



- Three microgrid sites:
 - Lakshadweep (*)
 - Brahma Kumaris World Spiritual University (+)
 - Dolimukh Village (+)

The CLOVER User Journey



Figure 1: CLOVER User Journey

Key References: Sandwell, P., Whetton, E., Nelson, J. "CLOVER: Modelling Microgrids for Rural Electrification", Grantham Institute 2016. Sandwell, P., Chen-Juan, A. & Nelson, J. Energy Procedia 132, 138-149 (2017).

Papers from Session 3

Urban architecture and the SDGs

The Circular Economy in architectural design as a contribution to achieving SDGs. Opportunities and strategies for urban Construction and Demolition processes.

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Abstract

The purpose of this paper is to throw light on the ways in which circular economy principles applied to the European architectural field can significantly enrich urban area sustainability, contributing to several of the goals identified by the United Nations, and to identifying the emerging obstacles needing to be addressed.

The first section explores the strategies designed to enhance resource efficiency in the building sector and analyses how reuse processes foster positive outcomes in several fields concerning SDGs, according to various sustainability perspectives and application scales. The second section of the paper describes reuse process outcomes in architecture, highlighting the related opportunities and the barriers preventing these strategies from succeeding. It will illustrate reuse design project phases and stakeholders and their workflows in detail, applied both at the single building scale and at the urban level, leading to the identification of priority areas to improve in order to increase the effectiveness of these practices.

By discussing the legal, market and governance improvements required, this analysis will suggest actions to be undertaken in order to enhance building element reuse as a sustainable architectural strategy.

Keywords

Keywords: Built Environment, Circular Economy, Construction and Demolition Waste, Reuse, SDGs.

1. Improving urban processes: the Circular Economy in the European construction field.

Due to current consumption patterns, based on linear models, and to the growth in size expected, cities are one of the priority areas in any pursuit of European sustainability and their urbanisation needs to be kept within environmentally sound systems. The building sector is one of the main players in urban processes and it is therefore responsible for much of their impact: its constant demand for energy and material resources and significant waste production, throughout the building life cycle, has to be addressed if its adherence to linear consumption patterns is to be acted on. Improving resource efficiency is thus fundamental to fostering sustainable urban development.

As the Ellen MacArthur Foundation research has proved (2013), achieving a shift towards a circular industrial system means focusing on the end-of-life concept: improving the durability of new products avoids the need for additional resource extraction, and encouraging reuse, refurbishment and remanufacturing allows products already in the market to circulate longer. Such strategies also apply to architectural design practice, concerning both recently manufactured products and components and those deriving from Construction and Demolition Waste (CDW): rapidly changing contemporary urban areas appear to be well-suited to the implementation of Circular Economy (CE) principles.

The importance of maximising the use of resources was also stressed in the waste hierarchy drawn up by the European Parliament in 2008, which concerns CDW management as well. This ladder is designed to establish “a priority order in waste prevention and management legislation and policy” for European member states that is “justified by life-cycle thinking” and encourages “the options that deliver the best overall environmental outcome”. Starting from these premises, practices such as ‘Urban Mining’ focus on according materials, products and components deriving from demolished buildings new value. In fact, designing reuse possibilities as a more environmentally efficient alternative to recycling, recovery or disposal processes, Urban Mining practitioners reintroduce such products into the building market without the need for a further manufacturing phase which, on the contrary, would require further energy and resources and cause further CO₂ emissions.

In this context, the aim of the paper is to describe and analyse the potential for applying reuse in architecture as a virtuous resource efficiency process designed to improve sustainable development in European urban areas. With regard to this, it is important to highlight that what is referred to here is not the use of recycled materials nor the limited use of various second-hand products in refurbishment – which ‘has long been undertaken in small-scale “domestic” building work and in some “heritage” projects, especially by making use of materials and goods available through the architectural salvage market’ (Addis, 2006). This paper will rather focus on the challenge of applying reuse processes on a larger scale as way of improving Construction and Demolition (C&D) work resource efficiency.

2. Reuse in architecture as a contribution to achieving SDGs.

The processes fostered by the CE have shown themselves to be an appropriate means with which to pursue certain urban sustainable development goals: Fig. 1 illustrates the implementation of these strategies on various scales, both positively influencing governance at the territorial level and improving material efficiency on the single building scale.



Fig. 1 – SDGs and their respective targets energised by circular economy processes in the building sector. © The UN Department of Global Communication

In the context of industrial manufacturing processes, the implementation of reuse and repair segments in the building market would represent a shift towards improved resource efficiency and contextualise growth within a green and innovative economy. The need to combine care for the environment with industrial development is stressed by Sustainable Development Goal (SDG) 9, whose objective to ‘build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation’ (United Nations, 2015). Moreover, target 9.4 specifies that a retrofit between industry’s current features, increased efficient use of resources and the adoption of environmentally sound technologies and processes will enable this goal to be achieved. On one hand, since reuse is the best environmental option in the CDW management hierarchy, its implementation in the building sector would avoid the need for further resource extraction and related CO₂ emissions, preserving the embodied energy (E_e) already locked in products and components. On the other hand, fostering the reuse process market would also generate construction sector employment growth, one of the fields most affected by economic crisis, opening up careers for both skilled and unskilled labour. This would also contribute to achieving SDG 8, and especially target 8.2 concerning ‘higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors’ (UN, 2015).

With regards to European cities’ material footprints and their environmental impact policies, fostering sustainable and efficient use of natural resources is fundamentally important. This means taking action against both resource demand and its inefficient management. Decoupling economic growth from resource use and environmental degradation is the objective of the 2030 Agenda set out in SDG 12 designed to ‘Ensure sustainable consumption and production patterns’ (UN, 2015). Such a shift ‘requires national public policies that create conducive environments,

social and physical infrastructure and markets, and a transformation of business practices along global value chains' (United Nations, 2018). The purposes of specific targets 12.2, 12.4 and 12.5 are sustainable management and efficient use of resources, focusing overall on those already transformed into products and later disposed of: waste. This perspective is fundamental where CDW is concerned, since it encourages prevention and reduction in order to decrease the demand for new resources to be introduced into manufacturing processes, as well as recycling and reusing, thereby enhancing current environmentally sound waste management practices.

Improving the building sector's reuse chain would generate further outcomes in other sustainable fields, in addition to the environmental perspective, such as the economic, social and cultural spheres. Emphasising the cultural aspect of sustainability was first undertaken in 1996 by the World Commission on Culture and Development (WCCD) which acknowledged that 'societies themselves create elaborate, culturally-rooted procedures to protect and manage their resources' and identified the importance of these procedures in the interaction between culture and the urban environment (WCCD, 1996). The debate related to adding a fourth sustainability pillar, the architectural field, in accordance with tangible and intangible concepts of heritage, leading to a recognition that:

'the role that building construction and the building themselves play in fostering regional and local culture traditions; supporting community life and the economy; and contributing to the texture and humanity of the built environment' (Powter & Ross, 2005).

SDG 11 'Sustainable Cities and Communities' states that 'Cities are hubs for ideas, commerce, culture, science, productivity, social development and much more' (UN, 2015). The main challenge is therefore for them to maintain this role 'without straining land and resources': this means preserving the environmental resources cities rely on as well as saving their cultural features. SDG 11's twofold vision emerges in target 11.6 concerning reducing 'the adverse per capita environmental impact of cities', and target 11.4 which points clearly at an objective whose aim is to 'protect and safeguard the world's cultural and natural heritage'. We completely agree with this perspective in the architectural field in which 'sustainability is not only a "green building" matter and the energy savings, environmental sustainability and governance aspects must be integrated with the preservation' (Condotta & Zatta, 2018) of the cities' unique features. This does not apply solely to listed buildings or monuments, but also to living spaces meant as 'a totality made up of concrete things having material substance, shape, texture and colour' (Norberg-Schulz, 1979).

The use of building materials based on recycling processes undoubtedly contributes to reducing cities' environmental impact on natural resources and the environment, but the use of reclaimed building components and products for new buildings, houses and developments can contribute more significantly to city and community sustainability. On one hand, in fact, by way of reuse, cities can renew themselves using "inner" components and products, closing the circle (Commoner, 1972), without importing raw materials from outside and thus reducing their material footprint. On the other hand, the use of reclaimed elements leads to a preservation of the "material substance", of the "texture" and "colours" of the urban fabric, both building interiors and public spaces such as streets, squares and neighbourhoods.

The practice of using reclaimed materials in renovation or conversion projects is already widespread, even though components are frequently reused with their original function. The example in Fig. 2 shows an improvement in this practice: the use of some old larch beams from a

demolished floor and some old cast-iron columns with a new function - to support multimedia and electrical equipment, to substitute the usual cable trays.



Fig. 2 – Reuse of old larch beams and cast-iron columns in an adaptive reuse project in Venice.

Nevertheless, the implementation of reuse practices in the design and construction of new buildings – and not just in renovation projects – is a more effective strategy than recycling, generating more significant natural resource saving and cultural city feature preservation. Fig. 3 is an example of the application of this strategy to the urban fabric: the façades of a building designed by Lendager Architects in Ørestad, Copenhagen, were built with sections of bricks walls from a former city brewery.

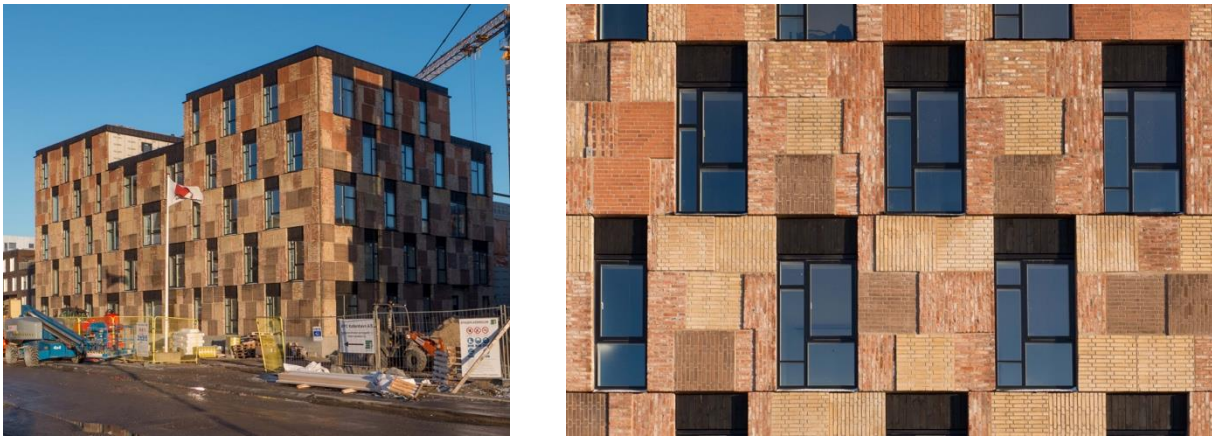


Fig. 3 – The “Resource Rows”. Construction phase and façade detail. © Danish Design Review.

On the basis of these analyses and arguments, it can be argued that the application of circular processes to architecture can significantly contribute to achieving certain SDG goals, but to different extents. Hence, while the use of construction materials with a percentage of recycled content (recycling) is increasingly commonplace, the use of reclaimed building components (reuse), a process with even greater urban sustainability potential, is a decidedly under-used

procedure. To make full use of this strategy, innovative action is needed both in the remanufacturing sector and in city policies.

3. Enhancing reuse in C&D urban processes.

3.1 Reuse strategies in the building sector

3.1.1 The “reuse design project”: features and centre-stage players.

Expansion in urban areas will inevitably accelerate changes in the urban fabric, involving infrastructure, neighbourhoods and public areas, with the goal of providing sustainable city and housing solutions for growing populations. This will lead to different levels of contemporary built environment action, depending on the features of the buildings worked on. Although, in some cases, design strategies such as refurbishment or adaptive reuse will enable the structure and fundamental traits of buildings to be preserved, in many others the original building will require more significant alterations and may even be judged unfit for its new purpose. These latter circumstances will mainly lead to the demolition of existing buildings with new ones being built in their place. In such cases, adopting reuse principles in order to activate SDGs while fostering resource efficiency would appear to be fundamentally important. The effectiveness of such a strategy will have to be supported by urban policies implementing material loops confined to the city boundaries as far as possible and encouraging reuse while preserving city cultural resources.

As Fig. 4 shows, applying reuse processes to a design project requires several interlinked phases, each involving different stakeholders.

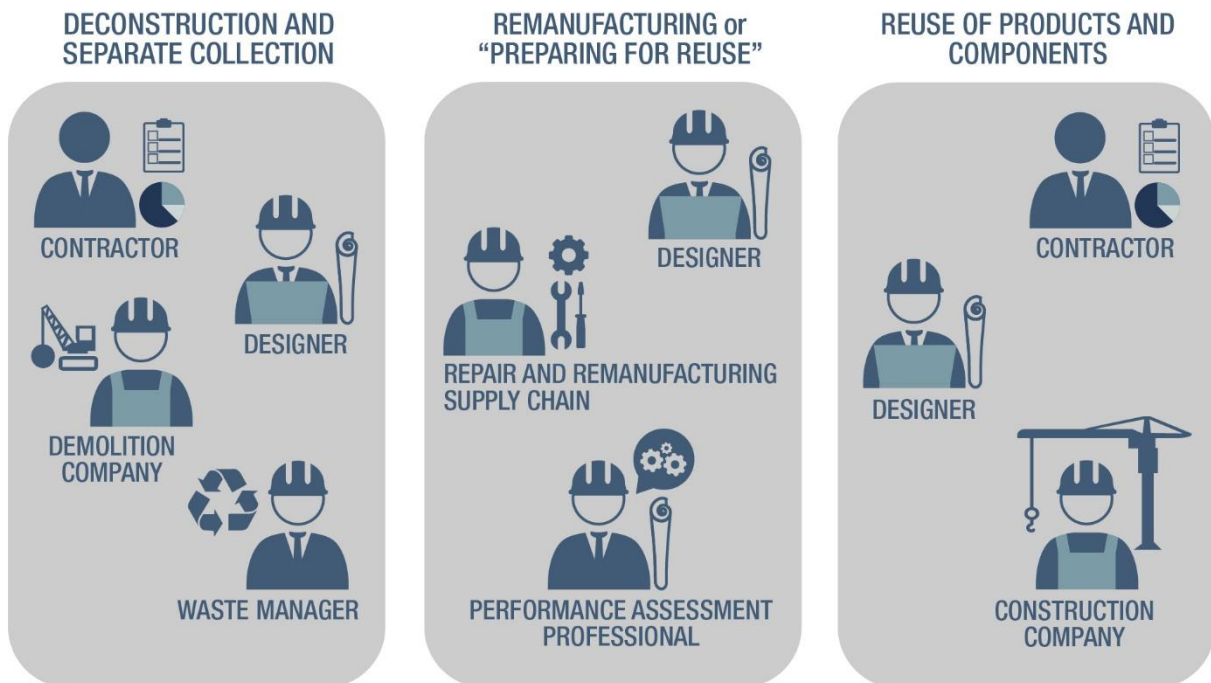


Fig. 4 – Phases and stakeholders in a reuse design project.

The first phase in any “reuse design project”– deconstruction - requires an initial survey to obtain adequate knowledge of the building concerned, its materials, products and components and their condition, in order to identify the most suitable strategies to apply. This pre-demolition building audit identifies the material parts workable, at best, for recycling as well as elements suitable¹¹⁹

for reuse. It is then necessary to choose the most appropriate technologies from those available to ‘mine’ these from the building. While demolition is suitable for portions of the building destined for recycling, efficiently dividing up products and components for reuse requires opting for deconstruction techniques, since these allow elements to be extracted intact. The manual operations required for selective demolition are more expensive as they have to be done by skilled labourers and require longer timeframes, but the potential for selling reclaimed products and components can compensate for the higher stakeholder costs involved. After recyclable materials have been separated out, the elements to be reused are catalogued and stored prior to their use in other construction work.

The second reuse design project phase deals with the potential need to remanufacture the reclaimed elements to enable them to meet the requirements of their ‘second life’. This process originates with a designer’s choices, since products or components can be used for different purposes from their original function and involves the repair and remanufacturing supply chain as well as a performance assessment professional – who may even be the designer him/herself.

EC Directive 2008/98 differentiates between “reuse”, as ‘any operation by which products or components that are not waste are used again for the same purpose for which they were conceived’ and “preparing for re-use”, meaning ‘checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing’. Whilst, on one hand, this definition widens the spectrum of elements potentially involved in reuse processes, including those considered waste, on the other hand, the precise moment in the life of an object which determines its ‘End of Waste’ (EoW) status is unclear. This legal indecision adds an element of uncertainty to reuse and remanufacturing market performance, exacerbating the lack of demand fostered by mistrust of “second hand” product quality. It is important to point out that, according to the European Construction Product Regulation (European Parliament, 2011), only elements meeting certain performance standards are considered fit for basic construction requirements, whether they are new or otherwise.

The third phase is the use of reclaimed products and components in other buildings: following designer instructions and investor/owner advice, construction companies take care of employing reuse elements in a building.

3.1.2 The “reuse design project”: circumstances and implementation.

This overview of the reuse design project has clarified the role of the various urban stakeholders in the process. It highlights the fundamental importance of the designer’s role in coordinating all the various phases and players, but it also demonstrates that a single architect’s will is not itself sufficient for a successful urban outcome.

For a better understanding of the circular economy’s improvement potential for urban renovation, regeneration and growth, analysing the implementation of the three phases in a building site may be useful. As Fig. 5 shows, this process takes place when a contractor is interested in demolishing a building and promptly reusing its products or components in a new building to be built on the same site. The main difference from a traditional design project is that the reuse purpose entails potentially remanufacturing the elements of the demolished building and storing them on-site: a precise previous plan concerning building site phases and storage management is thus needed.

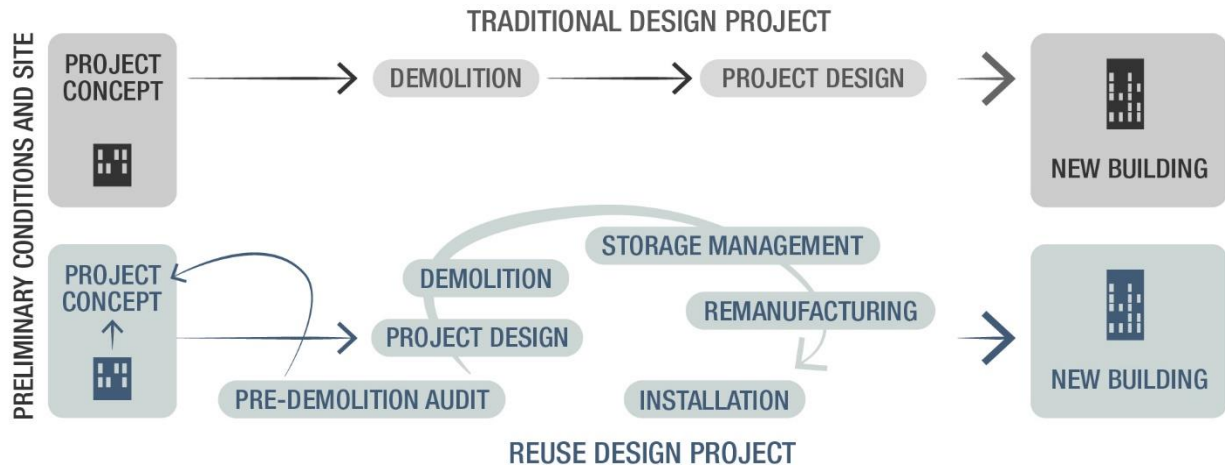


Fig. 5 – Comparison between a traditional design project and a reuse design project workflow.

Maximising the resources found in the building itself, this strategy is the simplest application of a reuse process as well as a rare situation. Clearly as it depends on the characteristics of the building to be demolished - the source of the reclaimed elements - this process is moreover defined by designers and contractors. These are, in turn, influenced by their socio-cultural sensitivity and by the market reaction to the reuse design project – understood as both potentially raised costs and the liking and acceptance of buyers. Alongside these planning and decision making elements, the main obstacles in this context are, therefore, those related to legal uncertainties, as described in the previous paragraph.

3.1.3 Closing the loop on a urban level

Improving the outcomes of this process requires broadening its boundaries to encompass a larger area: a neighbourhood, a district, even the whole city. This would allow CE strategies to operate on a different scale, fostering a more self-aware management of CDW as resources in urban governance policies. Urban Mining strategies are based on an in-depth knowledge of the buildings making up a city and aim to close the loop with an awareness of their specific features, materials and textures, thereby contributing to the city’s sustainable development.

As Fig. 6 shows, when enlarged to the urban scale, reuse design projects involve more buildings being demolished which are potentially “material banks”. This represents a further advantage: the potential for drawing building components from different sources, generating more options and greater flexibility during the design phase of the new building as well as in managing the building site. Moreover, in Urban Mining projects, reuse is not a matter of constructing a new building in the place of a demolished building but can, on the contrary, be replaced with other functions, such as public space roles. Although the larger scale process phases are the same as those of a single building, Urban Mining is a more complex strategy and its advantages are balanced by the obstacles to it: in addition to the legal and stakeholder constraints, the difficulty of this city level process lies in “scouting” reclaimed materials and components. In fact, generally no list of components that can be “mined” in a town exists and hence scouting has to take place at the same time as project conception and design, slowing down the construction process as a whole.

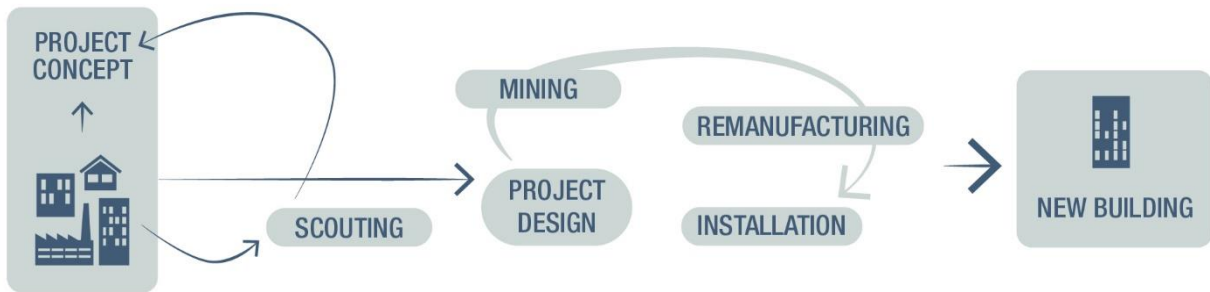


Fig. 6 – The reuse design project at urban scale.

‘The lengthening of project times’ and the consequent increasing of costs ‘due to the preliminary research phase and to the current uncertainty in the interpretation of waste regulations’ (Altamura & Baiani, 2019) are hence the most significant barriers to the implementation and dissemination of Urban Mining reuse practices in building construction.

3.2 Priority areas to improve

Reuse practices are slowly increasing in Europe but face several difficulties. Galvanising their contribution to built environment sustainability requires addressing the obstacles preventing their implementation. The analysis thus far has highlighted that the main barriers to the dissemination of reuse practices in architecture can be categorised into three main fields:

- legal vacuums and ambiguities;
- constraints related to stakeholder motivation and the market response;
- time-consuming and difficult scouting process.

The first of these requires action at both European and national levels. Resource efficiency has so far been addressed with a focus on recycling processes, leaving reuse without clear regulation or guidelines to follow. Fostering this environmentally sound practice requires clarifying its potential, dispelling uncertainties related to EoW status and tackling prejudices related to “second hand” . Although the performance of a certain product or component can be assessed, the inability to put CE marking on reclaimed elements is an obstacle to their market circulation. Legal improvements on this would foster the growth of the remanufacturing and reuse sector within a sustainable system and the creation of green jobs.

The second and third points, by contrast, can be addressed by promoting regional or city level action to positively influence reuse processes in the built environment. The stakeholder motivation and market response issues are crucial and need to be solved and this requires raising awareness among citizens. The importance of the circular economy in the building sector and reuse’s advantages in terms of sustainable production and consumption patterns are, of course, the aspects that need to be got across, but these are not in themselves sufficient. If, on one hand, awareness of the importance of resource efficiency is already present in Europe, on the other hand, the acceptance of reclaimed materials in homes is still a sensitive issue. Awareness campaigns are therefore needed at city level and city councils should give an example by promoting reuse in public building.

The issue of the time consuming nature of the scouting process also requires city level action but entails a completely different approach. Some recent research (Heinrich and Lang, 2018; Gepts et al, 2019) has addressed the theme of the urban building stock’s potential as a source of recycling material. Starting from existing building databases and 3D city models, these investigations give as output an overview of the material composition of urban building stock

and, consequently, the possible flow of materials to be recycled or reused. However, this kind of output does not facilitate the scouting phase. A different approach was used in the master plan for Musicon, a new district built in a former concrete factory acquired by Roskilde city council in Denmark. ‘Here the municipality commissioned to map the local area for material mining in a report suggesting which material components to keep, from which local buildings, and for which potential application’. (Manelius et. al. 2019) ‘Furthermore, the city has suggested empty facilities to store sourced materials to be reused instead of down-cycled’. This experience moves in the direction suggested here: local administration policies could potentially go one step further, creating a “program” of planned city demolitions and a related reclaimed materials “database”. In order to achieve this, as Fig. 7 shows, pre-demolition audits of all public and private buildings about to be demolished or renovated should be created.

To increase the effectiveness of these tools, economic incentives, assistance and other incentives, for both users and suppliers of reclaimed materials, must be planned.

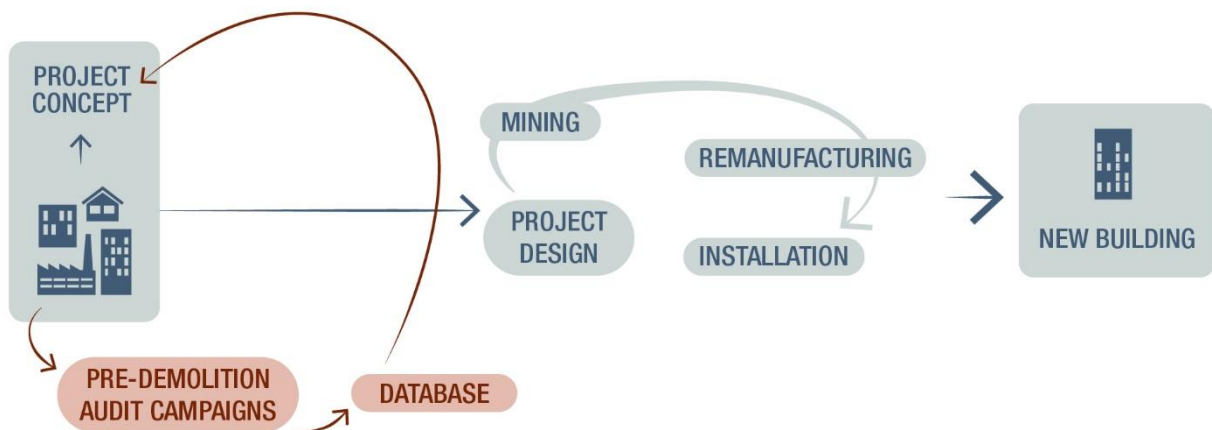


Fig. 7 – Urban scale reuse design project supported by pre-demolition audits and a database of potential and existing reclaimed materials.

Conclusion

At the end of this brief essay it can be argued that reuse strategies in the architectural field foster urban area sustainability, contributing to some of the SDGs set out by the 2030 Agenda for Sustainable Development with an impact going beyond the simple environmental aspect represented by ‘green sustainable architecture’. At the same time, multiple improvements are needed if reuse practices are to be activated and encouraged: the results of this preliminary analysis demonstrate that the technological processes required are ready to be introduced into the market, but that more governance, awareness and sensibility action is needed. The recent EU Construction and Demolition Waste Management Protocol (European Commission, 2016) would seem to be a focused contribution to this strategy, identifying CDW methodologies and procedures generating ‘major benefits in terms of sustainability and the quality of life’ and providing ‘major benefits for the EU construction and recycling industry’.

However, European, national and local policies are essential if city level actions are to be implemented and architectural reuse fostered, above all to free this practice from its current acceptance as a craftsmanship product, recognising instead its contribution to an agreed and shared “entire sustainable architecture”.

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VERNACULAR ARCHITECTURE AS A RESOURCE FOR RESILIENT COMMUNITIES

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Motto: „*The study of the relation between Humans and Nature is so old as the humans exists. Maybe is is the most fundamental science. We tempt to believe we have conquered the Nature, we control it, but we are lieing ourselves, as it should be better to came back to the Nature, trying to find an order in harmony with the rich and complex systems acoording to Nature.*”

J.O.Simonds, *Landscape Architecture*

Keywords: *vernacular, resilient, self sustainable communities, slow - development*

1. PURPOSE OF THE WORK

The paper refers the modes of intervention in concrete case studies, in order to integrate and valorize natural resources as solution for energy access in the architectural – urban dynamic, analyzing the potential of vernacular architecture to offer concrete solutions in nowadays context in urban areas.

The research is focused on the study of vernacular solutions for using green energies and for energy economy, analyzed in function of their climate, geographical and anthropic conditions. The study is made on urban zones which are supposed help for energy economy, through their geometric configuration, microclimate, location in relation with dominant winds etc. (ex. passages, inner courts, gangways coming out of the traditional tissue of Bucharest). The relations of this type of spaces with local communities and their needs will also be underlined to affirm a new model of slow development in resilient cities.

The paper underlines also vernacular solutions in order to enhance sustainability in an ecosemiotic approach. The perspective of the integrated valorization of the potential of a certain place implies a crossdisciplinary approach playing a key role within the architectural project, closely related and determinate for the urban planning policy, in the landscape management. The interpretative reading of the territorial systems, the recuperation of their historical role and the reconsidering of the aesthetic dimension of the landscape, are only few of the considerations within the architectural project strategy.

2. METHODOLOGY USED

- Reconsidering the value and potention of the *vernacular architecture* to offer solutions for nowadays approach regarding energy access for poor communities;
- Necessity to focus attention on *neglected landscapes*, as mentioned in the European Landscape Convention, Florence, 2000;
- Integration of spatial planning policies regarding these areas in the concept of *slow* –

development strategy;

- Integrated systems for the rehabilitation in order to recycle the existing architecture must take into account the urbanistic and the landscape context in close relation with the former socialist collective residence quarters. The *Collective Living* concept in this case belongs to the transdisciplinarity sphaera, crosses a wider domain, referring to urban planning, social and urban psychology, antropology, engineering, philosophy, semiotics, economy, geography, aesthetics.

3. MAIN FINDINGS

The paper configures an architectural and urban strategy, analyzing and finding some innovative ideas for some former socialist collective residential quarters, as well as for some old urban areas, proposing:

- Landscape interventions in order to recreate green areas, to prolong the green system;
- Design interventions for the re-naturing the envelope of the building, enhancing the performances of the building.

Vernacular architecture offers solutions and ideas regarding the modes of intervention in concrete case studies, in order to integrate and valorize natural resources as solution for energy access in the architectural - urban dynamic, to affirm a new model of slow development in resilient cities.

„A mistaken concept of universality would have led me to apply my mental categories of history and progress outside the context in which they developed, a grave error”. With these words mentioned as he was invited to design a cultural center in New Caledonia, Renzo Piano was not the first modern architect to discover and to acknowledge the relevance of vernacular architecture to his design ideas and practice.

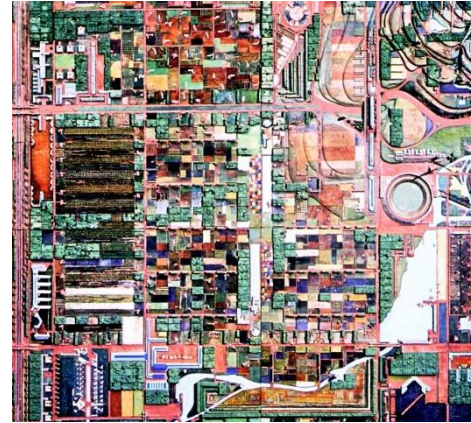
Le Corbusier made his journey to the „East” as he visited Romania, Serbia and Greece, impressed by the konaks, the wooden houses and the whitewashed walls and enthused over the decorative power that people and things take on when seen the white of peasant rooms.

Referring to European and Japanese vernacular architecture, Frank Lloyd Wright wrote: „folk building growing in response to actual needs, fitted into environment by people who knew no better than to fit them with native feeling”.

The result of the human – environment interaction constitutes culture and has led to the development of a multitude of cultures by different people in different environments. Vernacular architecture is one of the most concrete manifestation of this interaction, that not only solved the climatic problems, but did so with a combination of beauty and physical and social functionality.



Le Corbusier, *La ville verte*, 1935
Vegetation role in the Urban Design
<http://ocs.editorial.upv.es>



Frank Lloyd Wright, *Broadacre City*,
1934 – 1935,

The sinuous geometry of natural elements
merges with the regularity of built context
<https://www.iconeye.com/opinion/review/item/10315-frank-lloyd-wright-and-the-city>

Today, the loss of environmentally and socially conscious urban design also has to deal with the effects of climate change, which is becoming more aggressive where resource consumption has been the most furious and disordered. Modern landscapes measure dramatically the spatial success of such dynamics and the repercussions that these changes have on the life of cities and their inhabitants. The vulnerability of the city as read through the landscape should be confronted by designing innovative social, economic, and environmental responses that allow them to endure and form the basis for new landscapes. This means configuring and connecting fragments of the city together without nostalgic unitary visions or the fear of overwriting in order to reorganize the pieces, rereading and reinterpreting their connection to the context, recreating new places.

Resilient cities of the future must face several major challenges, which range from overcoming risks due to climate change (closely connected to progressively developing ecological imbalances) to the search for better energy conservation in the urban machine; from improvement in the quality and quantity of open spaces to returning residual areas (neglected areas, urban remnants, etc.) to the city. Thus far, there has been a lack of global solutions to improve the vulnerability of our cities or counteract external stresses that cities face now and will face even more in the coming decades. Faced with these profound changes, the rationalistic urban vision is no longer current. It is based on the monofunctional division of human activities and has led to the definition of plans and projects that are neither very effective in managing urban and territorial phenomena nor very adaptable in terms of external shocks caused by sudden climate, ecological, and economic changes.

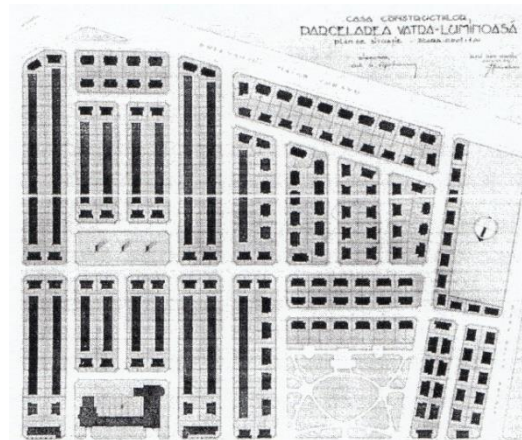
The Landscape concept in the spatial development moreover in the collective residential areas, implies a double aspect: lecturing and perceiving the landscape but also conserving, restoring and designing the landscape, involving the concept of *common good*. were considered to be examples of commons goods: landscape, historical / artistic / cultural heritage, biodiversity, water, cultural diversity. They have been the entry point to the cultural transformation of people, through the reconstruction of a link between these and the territory. The redevelopment of architectural and cultural heritage is a source of attraction of additional demand. Thus, the

landscape becomes an instrument of planning and designing the territorial spatial *slow - development*. The philosophy of *slow city* is precisely to offer a new path for local development trajectories compared to traditional development based on the centrality of “commons goods”.



Famous examples of plottings from interbelic periode as Jianu plotting, reconsidering the typology of garden surrounded by built space opened to the garden

<https://www.oar-bucuresti.ro/buletin oar>



Vatra Luminoasa plotting, 1933, Established system inspired by vernacular rural typology housing, as an optim relation between architecture and urbanism, resource for contemporary approaches

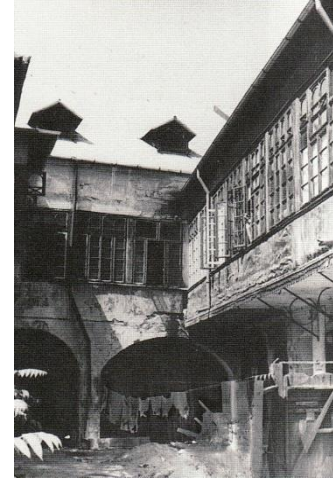
<https://www.oar-bucuresti.ro/buletin oar>

„ Regarding his tradition and his climate Bucharest should become a real *urbs in horto* and not *hortus in urbe*”, says urbanist Cincinat Sfințescu in 1932.

The old areas, that survived from the aggressive demolishing process in late ‘80 in Bucharest, let us discover the typology of the gardens surrounded by built spaces, a truly green scenery.



Dynamic of limits of built green spaces in relation with green spaces
Chlorophyll sceneries in the old area of Bucharest, [Source: author](#)



Traditional models for houses and inns: virtual transparence, arches, porches, specific details
[Source: www. word press](#)

Many times solutions for a sustainable urban life are to be found in the experience acumulated in vernacular architecture and traditional building techniques. Contemporary architects such as Alvaro Siza, Kengo Kuma, Shigeru Ban, Eduardo Soto de Moura, Peter Zumthor etc. are in a constant search of traditional principles to be applied to their projects, generating what we may call „the contemporary vernacular”. Also some solutions which proved their functionality can be adopted from urban patterns that have been constantly repeated, such as interior courts, covered galleries, opaque walls covered with ivy etc. Here are some categories of traditional urban solutions possible to be applied in the new strategies of development of the urban cities:

I. **Vegetation.** Sustainability is automatically associated with „green”, therefore vegetation, chlorophyll. About 100 years ago, in Bucharest there was a common practice to plant ivy or decorative grapevine on the blind walls (normally facing the north). The Saint George castle in Prague is a place that can be hardly imagined in autumn without the coloured vine covering the walls everywhere. Now we rediscovered „the green walls” in a much more complicated and expensive formula (for instance see the green wall at Caixa Forum in Madrid, by Patrick Blanc,

whose maintenance cost makes us wonder whether it is really sustainable). To go back to the traditional solution of planting climbing plants that grow spontaneously could be a challenge bring several advantages but also some threats. The advantages consist in: improving the microclimate of the building envelope, such as the surrounding area, aesthetic values and urban identity, including the building in a local „ecosystem”, creating more intimacy to living spaces, a chromatic relationship with the year seasons (in case of the blind walls covered with vine). Some threats brought by an excessive use of climbing vegetation are: excessive shading, avoiding direct sun, roots that affect brick masonry and the mortar deeply, keeping humidity in the mass of masonry, covering of some interior spaces, creation of a spatial network that can be accessed by animals or people.



Bucharest, Popa Nan street 32, the last dwelling of the famous singer
Maria Tănase

(Source: http://www.b365.ro/attractii-verzi-in-bucurestiul-gri-casele-imbracate-in-iedera-de-prinbucuresti-care-atrag-privirile_213958.html)

Other possibility to bring vegetation in the city is brought by „the garden roofs”, considered to be modern as defined in the theory of Le Corbusier. However let us observe the multitude of examples of traditional housing covered with straw or green grass – a prototype of the partially buried house that is found in several areas of tempered climate from the globe (from the Viking world to Japan, with a variation to be found in Romania with the name „bordei”). A contemporary attempt of reinterpretation for the green roof and offer it to the city as an element of public space has been conceived in 1993 by the architect [Philippe Mathieux](#) and the landscape artist Jacques Vergely that proposed an intervention of almost 5 kilometres of green itinerary at the height of the Parisian roofs of the XII-th arrondissement: *Promenade plantée*.

II. **The control of temperature. Microclimate of the building.** Maybe no urban solution is more efficient in cooling the space of a house than the historical „patio andalus” – interior court to be found in all houses of Andalusia, a hot region of Mediterranean climate in Southern Spain. The Andalusian patio is a direct continuation of the prototype of the *Domus romana* and of the Greek dwelling, both situated in warm Mediterranean contexts. The patio is the nucleus of a house, whose spaces are totally opened towards the interior. The key elements

of the patio are shading (given by the geometric configuration), vegetation (climbed on the entire height of the interior walls) and water – normally the patios had in the middle a fountain with constantly refreshing water (the fountain with water falling continuously is a microclimatic element in itself, typical for the oriental Muslim world and called *selsebil*). The configuration and geometric position of the Andalusian patio allows as well a constant air movement, with a continuous catching of fresh air from the street, through the high entrance portico covered with an iron rack and allowing warm air to raise and be eliminated through the high patio.



Patio from Andalusia (Source: <https://comunidad.leroymerlin.es/t5/Blog-de-la-Comunidad/Claves-para-crear-un-patio-andaluz/ba-p/54556>)

In temperate climate areas, contemporary architecture solutions have brought the idea of the covered ventilated interior court, created in order to preserve energy inside of the building instead of losing it (such is the case of the court of the British Museum in London, whose glass cover has been realized by Foster and Partners in 2000). Actually, while moving from the South to the North, the challenge becomes to preserve energy and increase the quantity of solar heat instead of throwing it away. In this case, the North of Spain brings us the specific model of „galerias coruñeses” – galleries from La Coruña, completely glazed surfaces orientated mainly to the South, able to capture a great quantity of sun and energy. The same traditional pattern may be discovered in the prototype of the Romanian inn (*han*), a typical construction with interior court and completely glazed walls that makes the identity of XVIII-th century Bucharest.

The glazed gallery has been interpreted in contemporary buildings as the double facade, a constructive solution applied to the majority of high-rise or public buildings today.

Other solutions related to the temperature control and energy conservation in dwelling spaces can be found in traditional model of the “caserio vasco”, a great one-family house designed to shelter the numerous family from the Basque Country, in Northern Spain. The construction shelters the animals of the family as well in the ground floor, this fact providing

natural heating for the main level of the house which is at the 1st floor, immediately about. Another vernacular heating system coming from Northern Spain is “la gloria”, a system of floor heating based on warm water used in Castilia and Basque Country, a direct heir of the Roman “hypocaust”.

III. **Natural ventilation.** Crossed ventilation is probably the easiest way to ventilate a space properly and simply. However there are several vernacular patterns which apply this system – one of the most interesting being the „barraca valenciana”, a type of long rectangular house in Valencia provided with only two openings on the short opposite facades. A key point is the orientation of the house towards the sea (west side), making possible the circulation of the sea breeze through the house.



Barracas valencianas (Source:

<http://adevaherranz.es/GEOGRAFIA/ESPANA/COMUNIDADES%20AUTONOMAS/VALENCIANA/?C=M;O=D>)

Another possibility is to use the effect of vertical air circulation, as in the case of the vernacular wind towers developed in the Islamic world and coming from a hot climate. There are several types of wind towers – with simple or multiple air flows, using or not the supplementary effect of water evaporation to refresh the air. The principle has been successfully applied to contemporary skyscrapers provided with natural ventilation.

IV. **Protection against the sun.** Maybe the most important element giving identity to the Romanian traditional house is the porch (in Romanian *prispa*). Present in all the climatic regions of Romania, as well in the warm fields of the south and in the hills or mountains, the porch aimed to provide continuity with the interior spaces of the house, offering a pleasant climate, protection from excessive sun and winds and an infinite view, providing connection with the whole surrounding landscape. It is not random that the first prototype of solar Decathlon was called „Prispa” and tried to be a contemporary reinterpretation of this architectural element.

The oriental world created its own way of protection against excessive sun, generating subtle decorative patterns and the prototype of the *moucharabie*, specific to the Arabian world. These elements were re-interpreted in new materials by contemporary architects such as Herzog and de Meuron (highest level of the Caixa Forum building in Madrid, with the façade protected by a perforated sheet in corrugated steel) or Jean Nouvel (with his original reinterpretation of

photographic diaphragms at *Institut du Monde Arabe* in Paris.)

Case Studies

1. **Ferentari Quarter** – situated in the southern part of Bucharest, built in the late '60 for the refugees of Chile, later inhabited by poor workers and roma, definitely affected by poverty and hidden criminality, nowadays appears as a ghetto improvisation result of enlarging of living areas, as the appartments are most of all one studio room, and the families count more than 5 members, remaining the rural manner of living.



Ferentari Housing Quarter built in the former socialist periode in Bucharest, 1968

www.wordpress.com

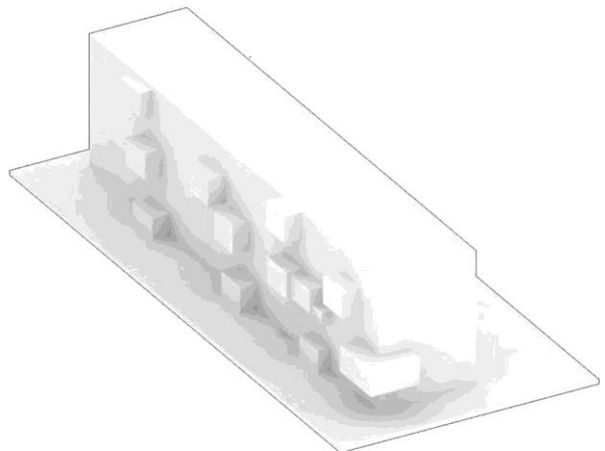
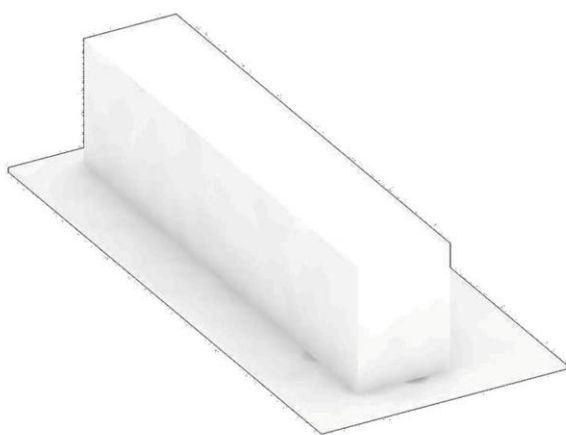
The proposal takes into consideration the original moder style and tries to improve the space quality, the inner comfort, the structure system and the urban image. It allowds also autonomy for inhabitants to intervent as they need. A second skin is created that increases the space within the appartments in a more structured and safe way, by terraces/balconies that can be enclosed as greenhouses, spaces within the grid of the structure being used for plants.

Depending on the urbanistic concept and the natural site conditions, the green areas, around the collective buildings, continued by the trees alignements along the roads, as far as they represent a continuum green system, related with the public parks, botanic or zoologic gardens, urban gardens, cemeteries and forests etc, will determinate and structure the metabolism of the residential areas and the city, relating to the macro-landscape, will determinate the *Living Quality* in a certain residential area, contributing to reduce the impact of urban heat islands in city quarters, but also the impact of other natural factors as wind or rain.

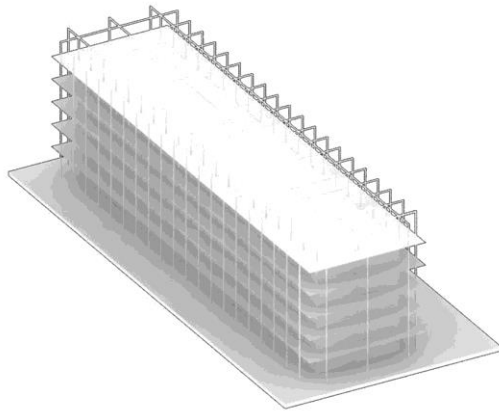


Nowadays statement: irregular enlargings, public spaces, shops, private gardens

Source: authors

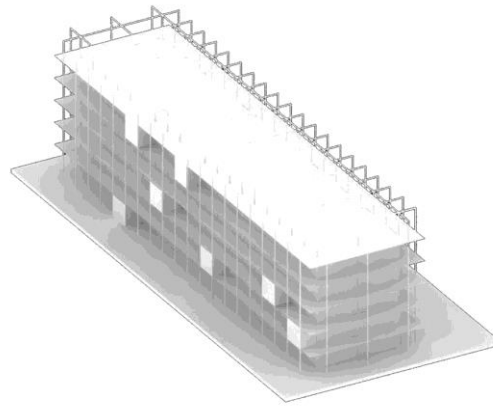


Original modern socialist building



Independent added structure

Irregular enlargings



Proposal with box - added enlargements

source: PhD stud. arch. Ana Mirea

The study configures an architectural and urban strategy, analyzing and finding some innovative ideas for this former socialist collective residential quarter:

- landscape interventions in order to recreate green areas, to prolong the green system;
- interventions re-naturing the envelope of the building, performances of the building;
- discussions with the local people as feed-back for the intervention strategy.

2. Mosilor Quarter Intervention

The case refers to a research project 'From City to Program: the Social Dimension of Architecture', in development at the Department of Basics of Architectural Design, Faculty of Architecture, 'Ion Mincu' University of Architecture and Urbanism in Bucharest, by studio team led by professor architect Dana Chirvai, Tana Lascu and Marius Solon. Focused on the reconsideration of what has become, as consequence of various unfortunate events in time, a neglected place, the project proposes a collective housing insertion, reconsidering a certain area in the context of a wider territorial system, belonging to the historical structure of Bucharest, extending the limits of the anachronistic concept of 'historical centre' to 'historical structure', proposing a insertion

Nowadays we discuss about the new urban systems as a laboratorium of higher living quality, beter integrated in the landscape, new ways of transport, new solutions for infrastructures and parking places with multicriterial analysis of the long term effects, pedestrian areas, new confort concept, to developpe special community public spaces, for interaction and communication, to give space to identity and the need to re-nature the city, to redefine the inter-relation Nature-human beings considering the humans as belonging to the Nature. Ventilation, green walls, green teraces, urban gardening and agriculture, bio systems to recycle the waste and the water, take part in the strategy for an ecocentric approach.

Some keys as starting point for research on this project are as considered:

1. Balance between built and open spaces, permanence of historical topographic traces, response of urban shape to climate conditions, the organic route, as result of the organic development of the urban structure;
2. Rhythm, scale, proportions, colors/materials / textures / height accents and detail

elements as bay windows, boundaries, iron mongeries, gates and balconies, porches, churches towers silhouette and spires;

3. Perspective typology, dynamic, with more axes, hidden/surprising/frontal/curved ends of perspective;
4. Open spaces, public spaces, with stable character or residual places – urban heat islands, mostly surrounding a building affected by demolishing processes, having potentiality to recompose public spaces and green areas;
5. Light, reflections of old façades in the new built curtain walls, relation between cornices design with sky, virtual transparency and spatial porosity.
6. The ecosemiotic issues regarding the interrelation with green system in order to improve perspective qualities by covering the blind walls as there are already some situations and to continue the former green network, according its climate and tradition.

Approach strategy has in view :

- elaboration of an inventory of landscape resources and architectural landscape resources and their evaluation;
- discovering the existent typologies in relation with the nature and culture, as reflected in the landscape;
- discovering and analyzing the way how some archetypal patterns still exist in territory and tempting to prolong them, in the spirit of preserving and developping some remanences, by starting mapping the built space in interaction with the landscape.

From the chorographic perspective, the urban landscape, doesn't mean only a scenery, but it represents a repository of the history either a sum of human experiences, offering different levels of reading and understanding the landscape, finding new network connections in order to provide new synergies.

The fundamental concept for a new perspective regarding the architectural project consists of a switch to a new vision from sustainable development to integrated sustainability, which has to consider the unity interrelations between anthropic and natural elements, material or not material, including all aspects, regarding economics, social-cultural, demography, ethic, environment.

Considering the aspects of integrated sustainability and formulating a matrix of interpretation of spaces qualities, as standards and values, the research tempts to offer a support for a real crossdisciplinarity, approach, regarding the interpretative reading of territorial sings, revealing the broad in between-ness concept.

Reflecting the crossdisciplinarity research methods, the attention switches from the individual objects to the history of the processes that have generated the objects, including exceptional landscapes but also common ones and even the residual ones, from the historical inventory to the dynamic evaluation of the transforming generated phenomena.

The concept of chorography, formulated by Dennis Cossgrove and Kenneth Olwig, reconsiders the Cultural Geography, continuing the ideas formulated by Christian Norberg Schultz. Referring to the existential space, Christian Norberg Schulz⁴ considers than a space gains the quality as an inhabited space when a human being living there can orientate and

⁴ Norberg – Schulz, Christian, *Genius Loci*, Pierre Mardaga Publishing House, 1986, p.186

identifying with his environment there. Simon Schama⁵ analyses the spirit of a certain place and the evaluation of certain rhythms, recognizing the equilibrium and the sensitivities regarding harmonic relations, included in the genetic codes and adapted to the environment conditions. Between a human being and his space there is established in time a meaning of belonging and the place, including its material essence, form, texture, colours, but also other coordinates, is determining in satisfying the cultural necessities for integrative symbols and the psychological need of spirit of place.

The perspective starting having in view the historical processuality, encouraged by the European Landscape convention (Florence, 2000), enhancing the awareness of the historical dynamics, being them still alive latent or disappeared, is essential for the study, for innovative strategic proposals.

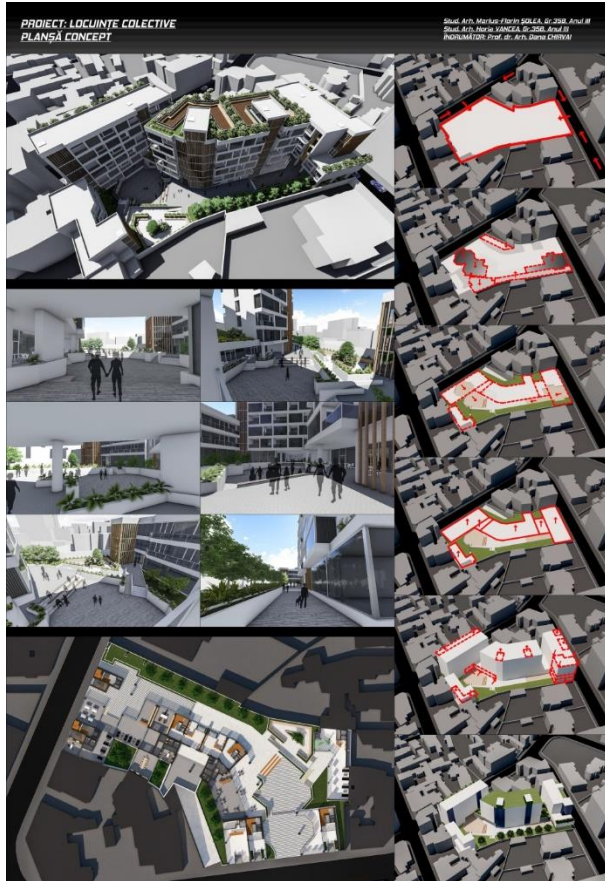
Specific spaces configurations and structured elements such as: cellars, vaults, lofts, attics, old rooms, window, the gallery, bridging public space, the street, and private space, the courtyard, become places of memory, carrying unique and strange signs, sacral or hierophanic. Horizons and new perspectives arising from modernization processes inherent in the city, transform the street space, into new labyrinths or gateways to initiatic paths.



Elements belonging to vernacular vocabulary transphered into eclectic architecture in the old area Calea Mosilor, [source: authors](#)



⁵ Simon Michael Schama (born 1945) is professor of history and art history at Columbia University. His work *Landscape and Memory* belongs to the New Cultural Geography current, started by Cossgrove in 1985.



Collective Housing Project, [source: stud.arch. Marius Florin Solea, Horia Vancea](#)

4. RECCOMANDATION FOR ENERGISING THE IMPLEMENTATION OF SDG by 2030
 - Focusing on the building performances, regarding saving energy by optimal spatial configuration, integrating principles of vernacular architecture;

- Enhancing living quality regarding comfort and facilities;
- Preservation of cultural identity - urban and architectural identity, in order to affirm a new development model that produces resilient cities via: - overcoming the mere conservation of the landscape, considering its evolutionary processes and the need to connect policies for the conservation of goods and natural and cultural resources with plans and projects for territorial transformation; - social participation in landscape management processes, since resilience is a process that cannot be completely planned and designed, but must be pursued by directing voluntary actions. As mentioned in the European Landscape Convention, attention must focus not only to high quality spaces but also to neglected landscapes.

The research concludes recognizing the system of values to reflect the spirit of the character of a certain place, appreciating its special rhythms, recognizing its balance and sensitivities, in order to detect, to preserve and to prolong the harmonic relations established in time, allowing communication of certain cultural values related to thinking, perception, emotional reactions and images, enhancing vernacular aspects.

Solar and geothermal energy for low-carbon space heating and energy independence.

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Abstract

In developed countries, space heating is highly dependent on fossil fuels consumption. Also, the non-renewable fuels combustion emits CO₂ which is claimed to impact the most on greenhouse effect. The utilization of Renewable Energy Sources (RES) for space heating, instead of fossil fuels, has been found to be feasible for systems' greater energy independence and reduction in CO₂ emissions. Solar Assisted Ground Source Heat Pump (SAGSHP) systems are a promising technology which can be used to accomplish the above framed target.

A mathematic model of a SAGSHP system was built and a parametric analysis for Birmingham which is a city located in the UK's West Midlands was conducted. Two scenarios based on two different dwellings were investigated, the one was a house recently erected and the other was a refurbished house. As regards the new house, simulation results showed that the utilized energy for space heating and Domestic Hot Water (DHW) can vary from 33% up to 73% RES dependent and, at the same time, electricity generation can be 2.21 times higher than the system's demand. As regards the energy renovated dwelling, the RES contribution to the delivered heat was found to be between the 33% and 63%, while the electricity generation did not result in any surplus energy from the consumed. Finally, by making use of SAGSHP system instead of a natural Gas boiler, the reduction of CO₂ emissions was found to be between 300kg/year and 2,170kg/year for the new building and from 245kg/year up to 3,221kg/year for the refurbished house, respectively. In both cases, SAGSHP systems proved to be a feasible practice for greater energy independence from non-renewable energy sources with substantial positive impact on the greenhouse gasses emissions.

Nomenclature

Subscripts	
<i>BHE</i>	Borehole Heat Exchanger
<i>FPC</i>	Flat Plate Collector
<i>GHE</i>	Geothermal Heat Exchanger
<i>GSHP</i>	Ground Source Heat Pump
<i>NG</i>	Natural Gas
<i>NGB</i>	Natural Gas Boiler
<i>PVT</i>	Photovoltaic and Thermal Collector
<i>SAGSHP</i>	Solar Assisted Ground Source Heat Pump
Nomenclature	
<i>Q</i>	Heat (kWh)
<i>E</i>	Electricity (kWh)

Introduction

In the European Union (EU), the domestic sector consumes 25.4% (EUROSTAT, 2015) of the total energy needs, while 64.7% of this amount is consumed for space heating and 14.5% for DHW. Over the past decades, the reduction on the energy used in domestic sector for space heating has been a major focus of researchers, governments and intergovernmental organizations, such as the United Nations (UN), with regards to the SDG 7 target. The need for more sustainable space heating systems with more dependence on Renewable Energy Sources (RES) and less on fossil fuels is important aiming at more environmentally friendly energy generation which can be accessible by all citizens.

The Solar Assisted Ground Source Heat Pump (SAGSHP) systems can utilize solar and geothermal energy in order to supply space heat and DHW to a building. A lot of effort has been made in order to investigate the SAGSHP systems feasibility. Therefore, SAGSHP systems like this of (Wang, Zheng, Zhang, Zhang, & Yang, 2010) have been built and investigated in real life conditions. The system is installed in China and after two years operation report a Heat Pump's COP of 4.29. Another investigated project was installed in France (Trillat-Berdal, Souyri, & Fraise, 2006), with its Heat Pump's calculated COP at 3.75 after a year. Moreover, SAGSHP systems were found to be a promising alternative choice for space heating systems in houses which are about to be refurbished. With projects like this of (Nicholson-Cole, 2012a), (Nicholson-Cole, 2012b) which illustrates how conventional Ground Source Heat Pump (GSHP) systems with unbalanced soil temperature can be transformed to a solar assisted one and improve the system's COP from 2.6 to 4.4.

Almost all SAGSHP systems in existing literature have been found to be comprised by different kind of components. For solar energy harvesting, Flat Plate Collectors (FPC) and Photovoltaic-Thermal (PVT) collectors are among the most efficient options. At the same time, for the geothermal part, U-type Borehole Heat Exchangers (U-BHE) is the dominant choice with the very shallow Geothermal Heat Exchanger (GHE) to be avoided due to their highly influence from ambient conditions. Nevertheless, systems equipped with PVTs can cogenerate heat and electricity simultaneously and that is an advantage against conventional solar collectors which are restricted to provide only heat. Therefore, the PVT option has been attractive for SAGSHP systems and installations like (Bertram, Glembin, & Rockendorf, 2012), (Bateson, 2014) and the one which described by (Naranjo-Mendoza, Greenough, & Wright, 2018) justify the interesting for this solution.

The SAGSHP systems' feasibility and parametric analysis is mainly function of the location, systems interconnection, control and components selection. As a multi-objective system, the design can be very complex, therefore computer-based simulations are recommended due to low capital investment and flexibility in investigated scenarios. In this work, a validated via experimental data mathematic model of a SAGSHP system has been created with TRNSYS (Solar Energy Laboratory, 2012). The built model was utilised in order to conduct parametric analysis for a system placed in Birmingham. The proposed SAGSHP system is consisted of PVT collectors and a novel very shallow BHE field. Furthermore, two types of single-family residences were investigated, a newly erected one, according to the L1A regulation for new domestic building, and a refurbished one based on L2A for energy renovated dwellings. Both building scenarios were found to be environmental and energetically feasible for the chosen location.

Methodology

System summary

An experiment of a PVT-based SAGSHP has been conducted by De Montfort University (DMU). The investigated experimental system combines PVTs with a novel shallow GHE and details about the aforementioned project can be found in (Naranjo-Mendoza et al., 2018). From the experimental procedure, data were used to analyse the system's operation and a SAGSHP validated mathematical model was created. Also, the model of PVT collector was based on further experimentation (Sakellariou & Axaopoulos, 2018) and as for the Heat Pump's model, performance data according to the EN 14511 standard, from a well-known German maker were utilized. Both dwellings, the new and the refurbished one, were built by employing the TYPE 56 on TRNSYS. In the new and retrofitted house, the underfloor space heating system was chosen as the heating mean.

In both houses, the new and the refurbished one, their occupied area is set at 120m². The parameters which characterize the buildings energy efficiency are listed in Table 1Table. Also, all windows are made from PVC double-glazing with overall U-value of 1.27W/m²K and the openings to walls average ratio is 0.138. Furthermore, the DHW is set to 140L per day at 50°C, which is a substantial quantity for a four-member family. The annual demand for space heating was calculated at 3,522kWh_{th} per year for the new house and at 9,741kWh_{th} for the refurbished one accordingly. Regarding the Heat Pumps capacity, a 3kW_{th} was chosen for the new house and a 4.8kW_{th} for the retrofitted. Finally, the DHW energy needs were estimated at 2,528kWh_{th} per year for both cases.

House type	Floor U-Value W/m ² K	Wall U-Value W/m ² K	Roof U-Value W/m ² K	Air Changes per Hour (ACH)
New Dwelling L1A	0.130	0.174	0.123	Set to 0.2 due to infiltration and 0.8 from mech-ventilation
Refurbished Dwelling L1B	0.250	0.288	0.175	Set to 1 ACH

Table 1. Dwellings thermal parameters.

The systems' main operation modes are shown in Table 2Table. Moreover, the electricity generated by PVTs is always injected into the electric distribution grid, while the power inverters' efficiency together with Joule losses on the cables are summarized to a total 10% reduction.

Schematic representation (heat flow)	Operation mode - Description
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<p>The diagram shows a house with a red roof and a red body. A heat pump is connected to the house. A PVT collector is shown above the house, with a red arrow labeled 'SOLAR HEAT' pointing down to the ground. A green arrow labeled 'GEOHERMAL HEAT' points up from the ground to the heat pump. The ground is labeled 'GHEs'. The house is labeled '*SPACE HEATING' and '*DOMESTIC HOT WATER'.</p>	<p>1. Heat pump operates and provides heat without solar heat contribution (no adequate irradiance).</p>
<p>The diagram shows a house with a red roof and a red body. A heat pump is connected to the house. A PVT collector is shown above the house, with a red arrow labeled 'SOLAR HEAT' pointing down to the ground. A green arrow labeled 'GEOHERMAL HEAT' points up from the ground to the heat pump. The ground is labeled 'GHEs'. The house is labeled '*SPACE HEATING' and '*DOMESTIC HOT WATER'.</p>	<p>2. Heat pump operates and provides heat with solar heat contribution via the GHE. (substantial irradiance in order to contribute in the house heating).</p>
<p>The diagram shows a house with a red roof and a red body. A heat pump is connected to the house. A PVT collector is shown above the house, with a red arrow labeled 'SOLAR HEAT' pointing down to the ground. A green arrow labeled 'GEOHERMAL HEAT' points up from the ground to the heat pump. The ground is labeled 'GHEs'. The house is labeled '*SPACE HEATING' and '*DOMESTIC HOT WATER'.</p>	<p>3. Solar heat recharging the soil (no need for space heating or DHW, thus the heat from the solar system is stored in the soil).</p>

Table 2. Systems main operation modes.

Parametric Analysis

Regarding the parametric analysis, it is conducted by changing the quantity of PVTs and the size of the GHE at every simulation. In more details, PVTs are set to vary from 0 to 20 by pairs of 4 PVTs in series hydraulically connected. For every PVTs configuration, the GHE is going to take 4 different sizes of 16, 24, 32 and 40 short BHEs at 1.5m long. Therefore, for each dwelling type, 24 simulations of 10-years period with simulation time step set to 1h have been executed. Also, the GHE is modelled to be installed beneath the house for the new dwelling, while for the energy renovated one the GHE assumed to be exposed and buried 0.5m below the ground.

The Renewable Energy Fraction (REF) which is the heat supplied by RES as ratio of the total delivered heat to the house (Fig. 1) is calculated for each simulation. Practically for the current system the REF can be calculated by dividing the heat added to the systems by the heat pump's evaporator with the delivered (eq.1). In other words, with the REF the contribution of the RES to the delivered heat is indicated. Furthermore, the REF can hold values from 0 to 1, with the meaning for zero to stand for no contribution at all of renewables on the heat load, while one shows a system running 100% from renewable heat. Lastly, it is practical to explain that the delivered heat on the load breaks down to three parts (Fig. 1), the heat absorbed by the Heat Pump, which is solar and geothermal heat, the energy added to the systems by the Heat Pump's compressor and the Auxiliary energy, if such is required.

$$REF = \frac{\sum Q_{HP-evaporator(1)}}{\sum Q_{delivered(1+2+3)}} \quad (1)$$

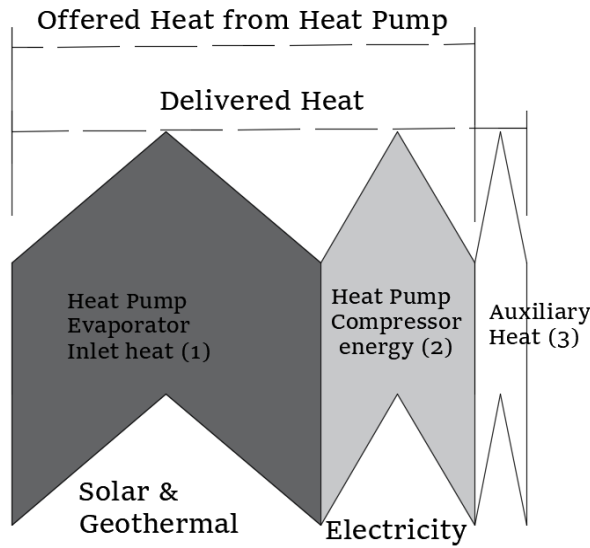


Fig. 1. Definition of the Delivered and Offered heat.

Accordingly, the Electricity Fraction (EF) is the ration of the electricity generated by PVTs divided by the consumed energy on the system (eq.2). The consumed energy consists of the electricity required for Heat Pump's compressor, the consumption of the circulation pumps and the consumption of the mechanical ventilation system. Contrary to the REF, the EF can be greater that one because generated electricity is directly offered to the grid and is not constrained by the consumption. For the investigated system, a net energy balance between the injected to the grid and consumed energy is assumed.

$$EF = \frac{\sum E_{generated}}{\sum E_{consumed}} \quad (2)$$

With regard to the system's environmental impact, the reduction of CO₂ emissions is investigated. The comparison is carried out by considering the proposed SAGSHP system against a Natural Gas Boiler (NGB). Regarding the NGB, it is assumed that it has to be designed to deliver the same amount of offered heat (portions 1 and 2 in Fig. 1) as the SAGSHP systems in every investigated scenario. In other words, the offered heat from the Heat Pump is going to be replaced by Natural Gas (NG) consumption. Furthermore, the NGB has average energy

efficiency of 88% and is capable to provide space heat at the same low temperature as the SAGSHP does, at the underfloor heating system.

The comparison, regarding the environmental impact between the two systems, is going to take place by subtracting the released CO₂ from the combusted NG to the amount which emitted by the SAGSHP system. Nevertheless, the offered heat by SAGSHP systems is comprised by the REF and energy added by the Heat Pump's compressor. Therefore, the CO₂ emissions for SAGSHP system are caused only by electricity because solar and geothermal heat have zero emissions. All the above-mentioned calculations for CO₂ emissions are described by equation 3 to 5, with the conversion factors to be 0.20399 kgCO₂/kWh for NG and 0.28088 kgCO₂/kWh for electricity (UK-Gov, 2018) . Lastly, the auxiliary heat is a common portion in both cases and thus does not considered on the comparison.

$$CO_{2_balance} = CO_{2_NG} - CO_{2_electricity} \quad (3)$$

With

$$CO_{2_NG} = \frac{\sum [Q_{delivered}] \cdot 0.20399}{0.88} \quad (4)$$

And

$$CO_{2_electricity} = \sum [E_{consumed} - E_{generated}] \cdot 0.28022 \quad (5)$$

Results

Simulations were conducted for a 10-year period with 1-hour simulation time step, but for illustrative convenience mean annual values are used. Also, all discussed parameters such as the generated electricity and the consumed heat were found to vary slightly from year to year during the simulation.

Based on equations 1 and 2, the REF and the EF have been estimated and illustrated in Fig. 2 and Fig. 3 for the new dwelling and the refurbished one, respectively. The REF is the portion of the total delivered energy, which has been fulfilled by solar and geothermal heat. In the same way, EF indicates the fraction of the consumed electricity, which has been provided by PVTs generation.

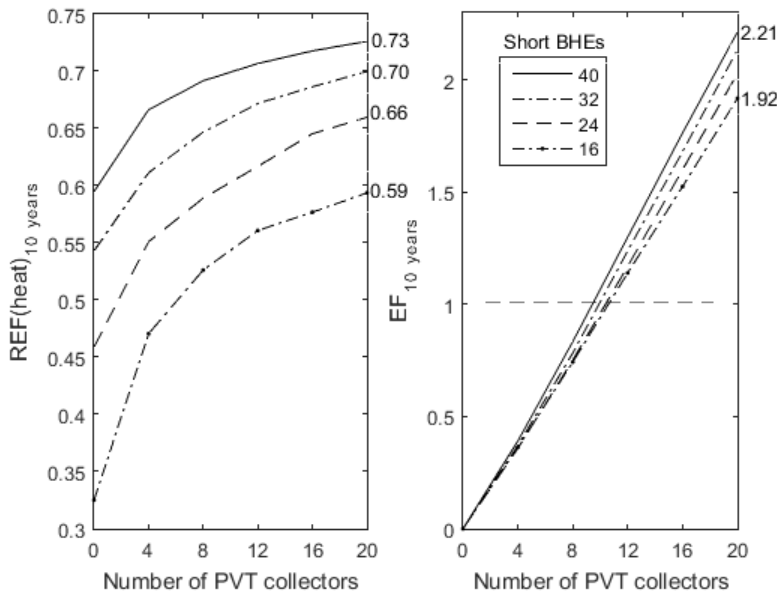


Fig. 2. REF and EF for the newly erected house as function of BHE size and PVTs quantity.

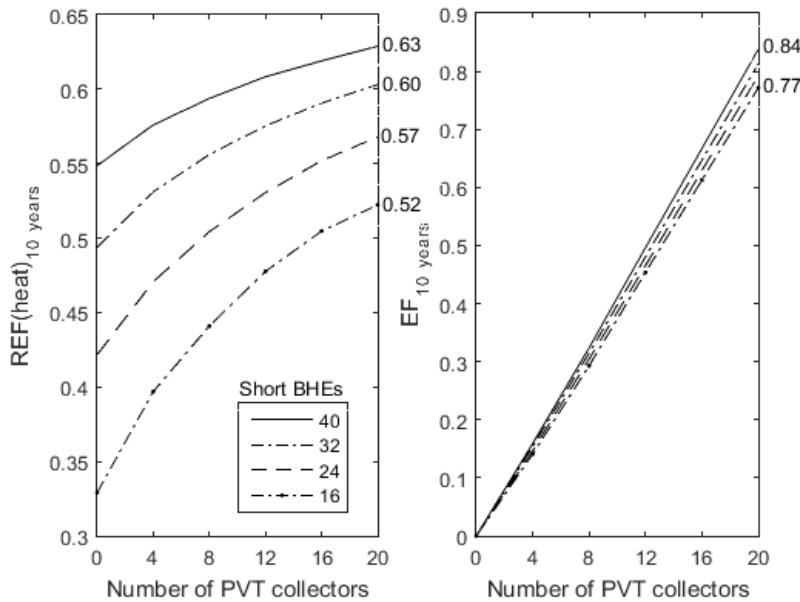


Fig. 3 REF and EF for the energy renovated house as function of BHE size and PVTs quantity.

The comparison between the SAGSHP system against the one replaced by NGB is taking place in Fig. 4 and Fig. 5, for the new and the refurbished house, accordingly. In more details, the reduction of CO₂ emissions for delivered heat is estimated by assuming that the equal amount of the Heat Pump's offered heat is replaced by NGB production (eq.4). Also, we have to bear in mind that negative emission gives a positive impact while negative are an actual released amount. In the investigated SAGSHP system, the Heat Pump's delivered heat is comprised by the renewable energy absorbed in evaporator and the compressor's consumed electricity. Also, the CO₂ released due to electricity consumption is based on equation 5, which indicates that by using PVTs' generation the CO₂ emissions can be decreased. Nevertheless, the electricity

which is required by the system to operate is the addition of the portion consumed by the compressor and the parasitic energy.

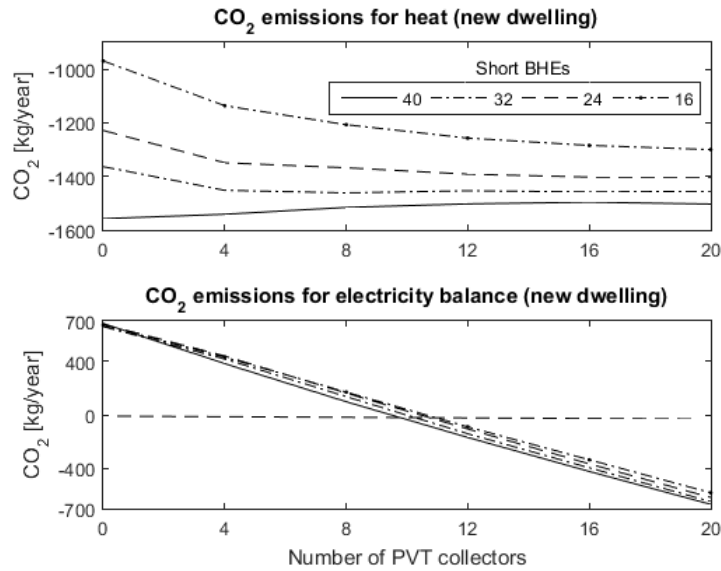


Fig. 4. CO₂ emissions from the heat delivered by SAGSHP systems against the NGB (eq.4) and the reduction of emissions by the electricity balance (eq.5), for the newly erected house.

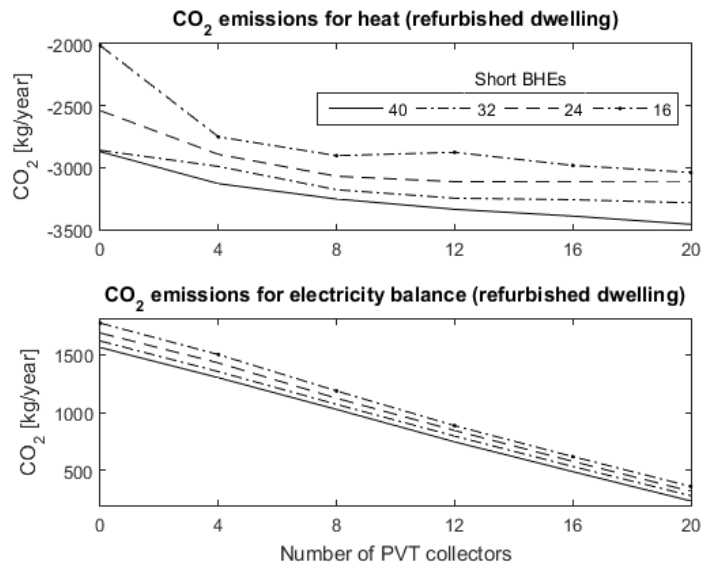


Fig. 5. CO₂ emissions from the heat delivered by SAGSHP systems against the NGB (eq.4) and the reduction of emissions by the electricity balance (eq.5), for the refurbished house.

Finally, the balance of the CO₂ emission between the SAGSHP and the NGB is shown by Fig. 6 for both dwelling scenarios. The CO₂ emissions, in both cases, have been estimated with equation 3, by considering the NGB's energy efficiency and the PVT's electrical efficiency.

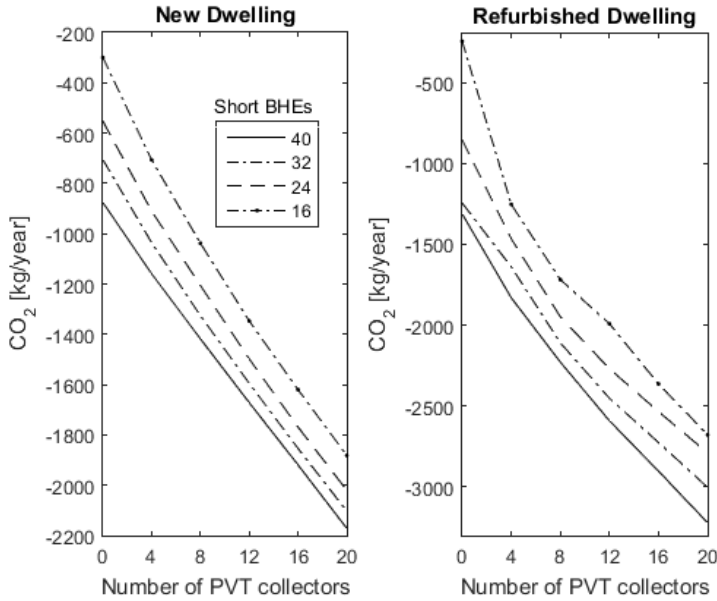


Fig. 6. Total CO₂ emissions decrease by utilizing the proposed SAGSHP systems against the NGB (eq.3). The comparison is for both dwellings and is illustrated as function BHE size and PVTs quantity installed.

Discussion

Regarding the newly built dwelling, the SAGSHP system was found capable of covering the 33% to 73% (Fig. 2) of total heating needs by solar and geothermal energy. About the refurbished house, the SAGSHP system managed to provide 33% up to 63% (Fig. 3) of total heating demand by RES. Nevertheless, the total energy demand for the new house has been estimated at 6.05MWh/year and at 12.270MWh/year for the renovated accordingly. According to the above-mentioned results, the SAGSHP system paired with the renovated house has managed to harvest more heat than the one with the new dwelling. That can be justified with Fig. 7, which illustrates the solar and geothermal energy entering the system for both houses as function of GHE size and PVTs amount.

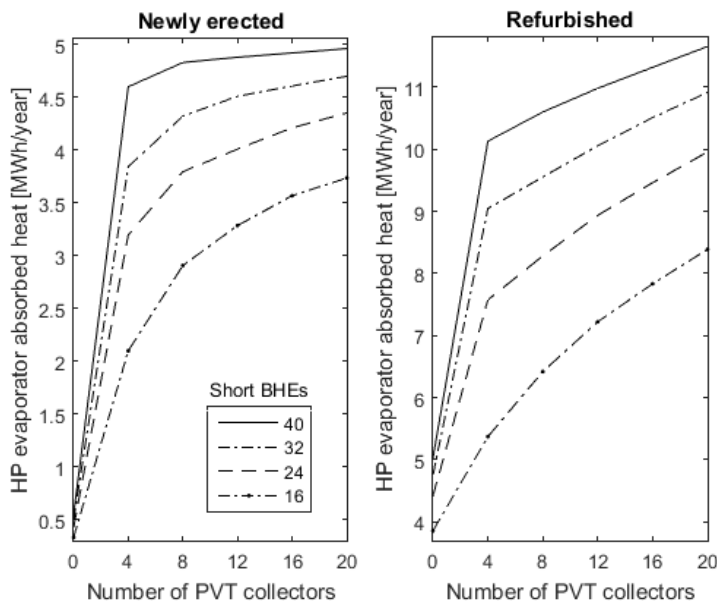


Fig. 7. Solar and Geothermal heat absorbed by the systems as function of GHE size and PVT amount.

Regarding the electricity balance in the systems, for the newly built house PVTs' electrical generation found capable to overproduce from the consumption after utilizing 10 collectors (Fig. 2). With the used PVT, which is rated at $235W_p$ and its electrical characteristics, the electricity generation was found to be 2.21 times higher than the consumption. Contrary to the newly erected house, the electricity consumed by the refurbished based system did not manage to generate more than the demand (Fig. 3). This is mainly caused by two reasons: firstly, the higher Heat Pump capacity ($4.8 kW_{th}$) for the renovated house against this of the new house ($3.0 kW_{th}$) and, secondly, the extensive operation hours in order to cover the more than two times higher heating demand.

According to Fig. 4 and Fig. 6, the newly built house gets negative CO₂ emissions in the whole of parametric analysis range. The total amount of CO₂ that is constrained from been released by using SAGSHP against NGB was found to vary from 300 kgCO₂/year to 2170 kgCO₂/year. Moreover, the electricity generation managed to decarbonize the emissions caused by the electricity consumption after using 10 PVTs collectors. By observing the CO₂ released by the heating part and the one which caused by the electricity (Fig. 4), the first amount was found to get high potentials to offer a positive environment impact. Finally, the parametric analysis, shown in Fig. 6 for the new house, illustrates that as the system get more PVTs to be installed and bigger GHE, the emissions decrease almost linearly.

Likewise the new house, the refurbished solution found to obtain a positive overall impact regarding the CO₂ emissions (Fig. 6). The discussed impact varies from 245 kgCO₂/year to 3221 kgCO₂/year with negative signed emission and is mainly due to heat decarbonization (Fig. 5). As it can be seen in (Fig. 5), the electricity did not manage to overcome the emission in the whole of PVT collector amount range. From results, the retrofit solution has achieved to decarbonize 1050 kgCO₂/year more that he newly erected house. Finally, the emissions reduction was found to follow the same linear trend with the new house, when the PVTs number increase or the BHE size become bigger (Fig. 6).

The analyzed SAGSHP systems are potential solutions in regard to the UK's targets for 100% electricity virtually made by RES by the 2050 (DECC, 2009). Also, the proposed systems, may assist on the UK's targets for reduction on CO₂ emissions and the energetically improvement of the existing houses. Based on the aforementioned two cases, the new market may offer employment opportunities during the construction, operation and maintenance.

Finally, the work's primary UN target is related to the energy sustainability (SDG7), but wen houses are equipped with RES the hole city may benefitted from that (SDG11). The reduction of CO₂ emissions and the replacement of fossil fuels with RES technologies improves the citizens energy accessibility. Moreover, the installed SAGSHP systems can operate as prototypes for students to learn about low-carbon housing. The education of young people about the environmental problems and the practical solutions makes them more aware regarding their way of thinking (SDG13).

Conclusion

In this study, a parametric analysis of a SAGSHP system with experimentally validated model was conducted. Based on findings, the proposed SAGSHP systems can be a viable solution for new low-rise dwellings or for retrofit. It may also be applicable to other building types. In more details, in the case of a nearly erected dwelling with the proposed SAGSHP system, the heating needs can be fulfilled by 33% up to 73%. Accordingly, the proposed system with the

refurbished house was found capable of similar energy independence which starts at 33% and it can be as high as 63%.

Additionally, in the case of the new house, PVTs managed to overproduce from the system's consumption and export electricity to the electric distribution grid. In more details, the PVTs managed to generate 2.21 times more electricity than the consumed by installing 20 PVTs, while the system was found to get balanced by using 10 PVTs. The SAGSHP system based on the refurbished solution did not get any better than cover the 84% of the electricity demand. In the refurbished house, the EF can be increased by many ways, but the most straightforward is to increase the PVTs electrical capacity and, by that, to obtain higher generation.

Moreover, both investigated systems were found to get negative CO₂ emissions for the whole of parametric analysis range. The higher potential for CO₂ emissions reduction was obtained for the retrofitted house with 3,221 kgCO₂/year, as for the new one, the best value was 2,170 kgCO₂/year. It was observed that CO₂ emission drop linearly as the installed PVT capacity increased or the GHE became bigger. Finally, the energy and environmental sustainability can be achieved by the proposed system as it is proved be the case by this study. The aforementioned targets are among the EU's and UN's priorities which are to ensure access to affordable, reliable, sustainable and modern energy for all.

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Papers from Session 4

Renewable Energies and the SDGs

An empirical study of the variation of electrical output from photovoltaic-thermal solar panels

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Abstract

The purpose of this research was to analyse the effect of forced cooling upon the electrical output of photovoltaic-thermal (PVT) solar panels. Sunlight on solar PV generates electricity but it also heats the panel, tending to reduce output. Forced cooling can increase generation and provide a source of valuable heat. Some have claimed enhanced energy performance from PVT compared with conventional PV, but most studies have been lab-based. This paper reports a study of the performance of PVT panels operating as part of a heating system including heat storage and extraction to serve a domestic building. Seven PVT panels were mounted on a house in Leicester next to a single PV panel of the same specification (but without forced cooling), and their electrical performance compared over a four-year period. The results show that the average PVT solar panel underperformed over a year by approximately 3%, with the difference varying by season. The average PVT panel slightly outperforms the PV panel in summer only. This result is relevant to SDG7 and potentially to SDG6, since PV delivers affordable and clean energy in developing countries and may be applicable to water purification, although this paper does not describe the latter in detail. In hotter climates, the enhanced performance of PVT may be worth the added complexity of cooling, but only if the heat is valuable and can be extracted so that the panels remain cool.

Acknowledgement

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Keywords

Photovoltaic-thermal hybrid, solar panel, PV, PVT, forced cooling, SDG7, SDG6

Introduction

Hybrid photovoltaic thermal (PVT) technology represents a space-efficient approach to solar collector design for installations in which both electrical and thermal energy are needed. This is because they can make use of much more use of the incoming solar energy than conventional photovoltaic (PV) collectors alone. Of the approximately 90% of solar irradiation that is absorbed by a solar cell, only about 15% is converted into electricity while the rest is absorbed as heat, which raises the temperature of the collector and is subsequently lost to the environment by radiation and convection (Michael et al, 2015; Good et al., 2015). In relatively cloudy and temperate climates such as the UK, the raised temperatures and their impacts on efficiency are modest even in summer; but in hotter, sunnier countries such as India the temperature rise of a PV collector can be significant. In such conditions, forced cooling beyond that possible by natural convection and radiation alone can increase electrical efficiency by as much as 9% (Preet et al., 2017). PVT technologies are therefore able to increase the electrical output of a solar collector as well as generating useful thermal energy.

Literature review

There are different approaches to PVT collector design, of varying complexity and most of them are discussed and compared by Michael et al (2015). PVT collectors may be glazed or unglazed and most have some form of thermal insulation. All PVT collectors resemble conventional PV

collectors with fluid (air or liquid) forced through a network of channels behind the solar cells to cool them. Glazed PVT collectors operate at higher temperatures than unglazed designs (since they more closely resemble solar thermal collectors than solar PV) however these higher temperatures may reduce electrical efficiency. Such designs may therefore be more suitable for installations where thermal efficiency is a priority, such as Northern Europe. There have been several studies of different designs of PVT collector that compare them with both conventional PV and combinations of PV and solar thermal collectors. These studies aim to identify the optimum combination of technologies to generate electrical and thermal energy from a given roof space (Good et al, 2015; Dupeyrat et al, 2014; Othman et al, 2013; Pathak et al; 2014; Preet et al, 2017; Dott et al, 2012). Many researchers have studied the performance of PVT collectors as part of larger integrated energy systems, including some highly innovative systems such as that described by Wang et al. (2019). In their paper, the authors describe the use of the electrical output of PVT collectors to power the production of hydrogen using a proton exchange membrane (PEM) electrolyser, while the thermal output pre-heats the water used by the electrolyser. This has the effect of increasing the exergy efficiency of the electrolysis process while simultaneously cooling the PVT collectors, increasing their electrical efficiency. Note that this system featured open loop cooling of the PVT since the electrolyser converts the coolant that leaves the panels into hydrogen and oxygen, replacing it with fresh, cooler water instead of recirculating it.

Since PVT collectors tend to operate at lower temperatures than solar thermal collectors do (especially if unglazed), energy system designers sometimes combine them with heat pumps in systems where domestic hot water is required (Dott et al, 2012). Some such systems allow the PVT collector to supply the evaporator of a heat pump or to heat a tank of water directly if the PVT temperature is high enough. One advantage of supplying heat directly to a tank is that the PVT system is able to take advantage of stratification, so that fluid returning to the collector may be significantly cooler than that supplied by it to the tank, providing the necessary cooling effect to the PV cells. However, in cases where such systems stagnate, as with any solar thermal system the temperature of the collector will rise. The presence of stagnant, warm coolant within the collector (with the temperature maintained by insulation in some designs) means that the temperature of the solar cells may rise significantly above the temperature of an identical PV collector under the same conditions. Therefore, systems featuring PVT collectors that recirculate coolant in a solar loop will sometimes experience warmer semiconductor material and hence reduced electrical efficiency compared to conventional PV. One of the aims of system designers is to minimise the occurrence of such conditions.

Seasonal heating systems

Several authors have evaluated heating systems that combine PVT collectors, heat pumps and thermal storage (Dott et al., 2017, Cai et al, 2017) but few have evaluated systems designed to store the excess heat generated in summer and use it to supply a building in winter. The Drake Landing solar community in Canada uses a large seasonal store with 144 boreholes to store heat from solar thermal collectors, with a water filled buffer tank to deal with heat flows that fluctuate more rapidly than the borehole thermal energy storage (BTES) is able to accommodate (Sibbitt et al, 2015). This system does not use heat pumps since it is designed to store heat in the BTES at up to 80°C. Wright et al (2014) discuss the design and operation of a 'net zero carbon' energy system for a domestic building. This system uses shallow boreholes (1.5m deep, spaced 1.5m apart) to store low temperature heat from PVT collectors most of which is generated in summer, that is then withdrawn by a heat pump to supply space heat (mainly in winter) and domestic hot

water. The use of extremely shallow boreholes and the inter-seasonal design are the principal innovations of this type of solar assisted ground source heat pump (SAGSHP) system. By extracting heat from the solar collectors during warmer months and pumping the stored heat to the evaporator of the heat pump, the system is intended to increase both the electrical output of the solar collectors and the CoP of the heat pump. This system is the focus of this paper. We report a comparison between the electrical output of a single solar PV collector and that of seven unglazed PVT collectors that are identical electrically, but which feature liquid cooling and insulation.

Experimental methodology

Unlike the energy system described by Wright et al (2014), which is designed for use on new-build properties, the system described in this paper has been retrofitted to an unoccupied terrace house. This building has been upgraded with loft insulation and double-glazing to modern standards but it has no cavity or solid wall insulation, so it is relatively inefficient. As this is a retrofit system it was not feasible to install the thermal store, known as an ‘earth energy bank’ (EEB), within the foundations of the house, as is normal in such installations. Instead, the builders created a thermal store of the same footprint in an adjacent grass verge. They reinforced the sides with concrete as if they were the footings for a new-build house and insulated the EEB at the edges and on top. The energy system pumps warmed fluid from the thermal side of the PVT collectors into the EEB using a conventional solar thermal loop, and withdraws the heat when needed using a heat pump. The experimental system was intended to allow the study of different aspects of the system performance such as the electrical efficiency of the solar collectors, the amount of heat that can be stored and retrieved from the EEB and the seasonal performance of the heat pump. Figure 1 shows a diagram of the installed system.

[Installation of solar collectors](#)

The PVT collectors are based on the Romag RSM series of polycrystalline PV collector. The semiconductor material is sandwiched between a toughened glass front cover and a sheet aluminium absorber with welded tubes in a ‘harp’ arrangement with a hot and cold header. The thermal absorber is insulated with a closed cell foam rubber sheet approximately 5mm thick. Eight solar collectors were installed with seven being PVT, whilst the eighth had an identical solar PV component but no thermal absorber or insulation. All eight were equipped with SMA micro-inverters so that their electrical output could be recorded individually and compared. The collectors are arranged on the roof as shown in Figure 2 in which number 8 is the PV collector. The fluid connections to the PVT collectors are arranged as shown in Figure . It was understood at the time that this combination of series and parallel connections of the coolant pipes is sub-optimal from the point of view of panel cooling, but the arrangement was chosen for simplicity and to investigate the effects upon electrical efficiency.

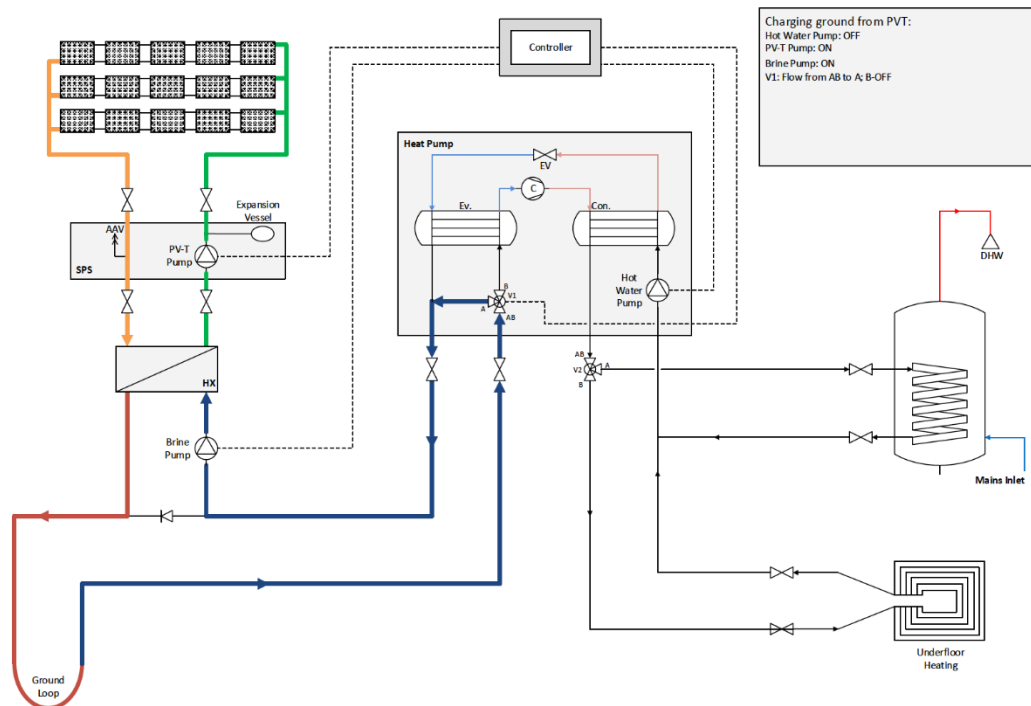


Figure 1 - Schematic of the experimental heating system

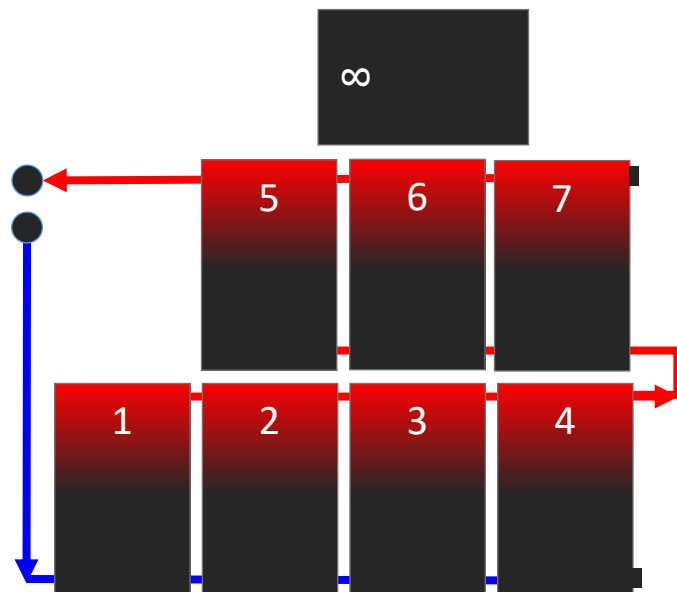


Figure 2 - Hydraulic connections and location of PVT and PV

Measurement and data collection

Both the electrical output and the thermal output of the panels is measured, the former using data from the micro-inverters and the latter using data from the solar thermal system, which is also reported to a web portal from where it can be observed and downloaded. The electrical output data from each micro-inverter are stored in SMA's 'Multigate' device that communicates with 157

a web portal from which data can be downloaded for analysis. The web portal also allows the analyst to download tabular data for every day's generation by each micro-inverter. The author has done this for every day since the system was installed on the 16th September 2015, and the results are presented below for discussion. Unfortunately, there was a loss of data between 21st April 2017 and 20th May 2017, but this does not seem to have skewed the comparisons between PV and PVT collectors significantly when compared with 2016 data.

Results and analysis

The most productive and least productive months tend to be July and December respectively. Figure 3 shows the electrical output of all the panels on a sunny 17th of June 2017. One can see that the differences in electrical output are small and that there appears to be no appreciable shading of any particular panel that would cause its output to deviate from those of the other panels. In the afternoon, the output of the PV panel appears slightly higher than that of the PVT panels. In fact on this day, the SMA utility shows that the PV panel produced 1.422 kWh whereas the average PVT produced 1.457 kWh, a difference of 2.4% in favour of the PVT, suggesting a small benefit from forced cooling on a hot sunny day. However the data for the entire month show that the advantage of the average PVT panel over the PV was only 0.1%. Figure 4 shows the electrical energy captured by each collector over the entire history of the installation to date. The differences are small, but the single PV collector has outperformed all the PVT collectors in each year. Table 1 shows the outputs for every day in July 2017. For each day, the least productive collector was number five and the most productive overall was number eight, which is the PV panel. Panel five receives warmed fluid from the other six PVT collectors, which may explain why it is always the least efficient panel. The difference between the energy collected by the PV and the average PVT collector during July 2017 was 1.3%, so although the PV panel performed slightly better electrically the difference was very small, and of course, it generated no useful heat, unlike the PVT collectors.

Table 2 presents a comparison between the electrical generation of all panels since installation in 2015. One can see that in each year the average output of the PVT panels has underperformed the single PV, but that the PVTs tend to perform better in the summer months. One would expect this to be the case, because it is then that the effects of forced cooling will be greatest. It is also then that the electrical output of all panels is maximised which helps to compensate for the reduced output of the PVT panels during the winter and shoulder months, so that in a typical year the electrical output of the average PVT panel is reduced by approximately 3% compared to an equivalent PV panel.

Discussion

The temperature of the coolant flowing through the solar PVT collectors was monitored and was found to reach approximately 40°C in the hottest periods. This is when the majority of the heat captured by the seasonal heating system is being stored in the earth energy bank. Observations of the system in operation have shown that during the summer heat capture period, the rate of heat transfer into the EEB is sufficient to raise its temperature to about 22°C. Once the EEB has reached this temperature the rate of heat transfer slows considerably so that the coolant tends to return from the EEB to the solar collectors at barely reduced temperatures. It seems that the system is capable of cooling the solar collectors effectively in the summer months, but that much of the heat does not transfer effectively into the EEB. Instead, it returns to the collectors where it is transferred to the environment by a combination of radiation and convection, and it is therefore wasted.

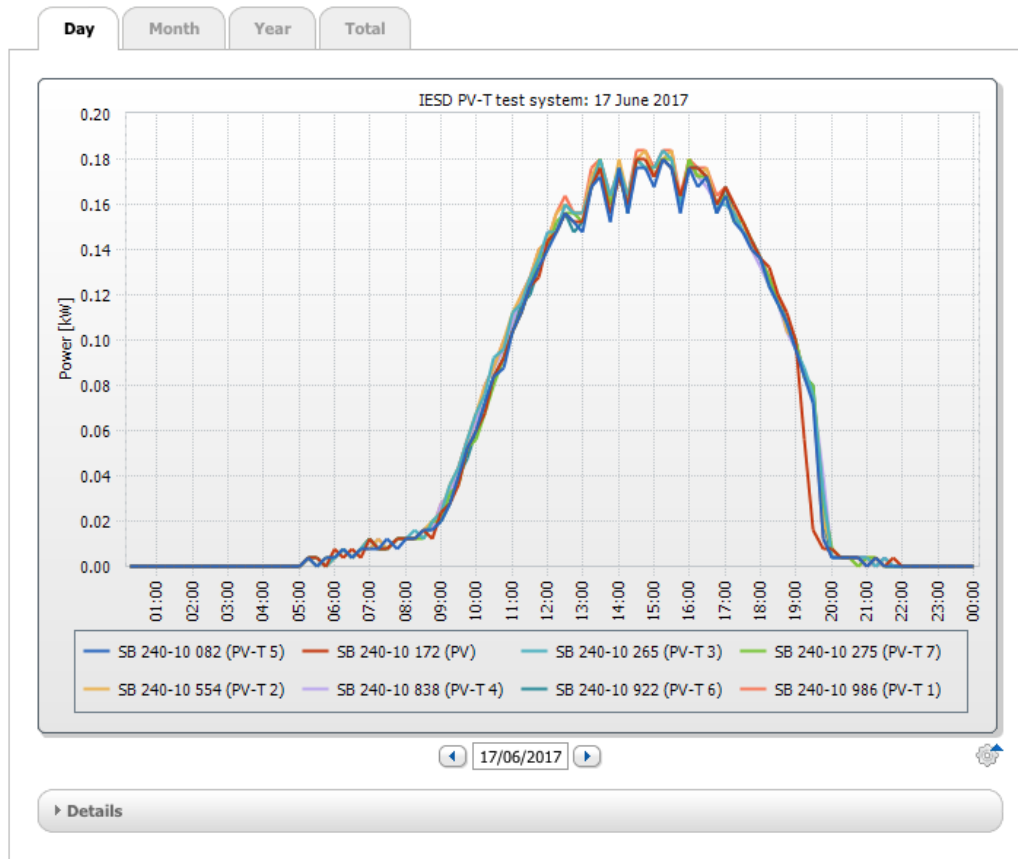


Figure 31 - Electrical power from seven PVT collectors and one PV collector

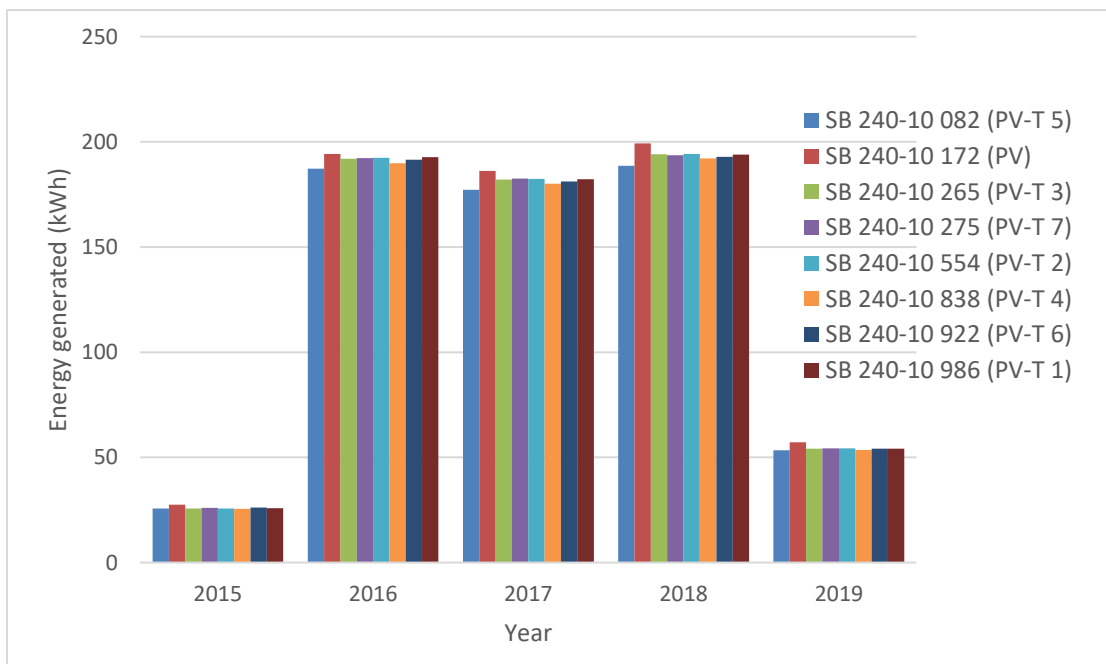


Figure 4 - Electrical energy from seven PVT collectors and one PV collector

PV inverter energy data by day for July 2017										Max in green, min in red		Daily Energy			
Date	5 (PV-T)	8 (PV)	3 (PV-T)	7 (PV-T)	2 (PV-T)	4 (PV-T)	6 (PV-T)	1 (PV-T)	Total	Max	PV energy	PV-T average	% Diff		
01/07/2017	1.011	1.06	1.05	1.05	1.051	1.041	1.036	1.051	8.35	1.06	1.06	1.0414286	-1.8%		
02/07/2017	1.388	1.423	1.429	1.425	1.433	1.415	1.414	1.434	11.361	1.434	1.423	1.4197143	-0.2%		
03/07/2017	1.034	1.082	1.081	1.079	1.084	1.072	1.064	1.082	8.578	1.084	1.082	1.0708571	-1.0%		
04/07/2017	0.726	0.77	0.763	0.762	0.761	0.758	0.753	0.759	6.052	0.77	0.77	0.7545714	-2.0%		
05/07/2017	0.827	0.849	0.865	0.853	0.866	0.855	0.846	0.864	6.825	0.866	0.849	0.8537143	0.6%		
06/07/2017	1.073	1.101	1.116	1.107	1.12	1.107	1.096	1.12	8.84	1.12	1.101	1.1055714	0.4%		
07/07/2017	0.675	0.71	0.716	0.704	0.716	0.708	0.694	0.712	5.635	0.716	0.71	0.7035714	-0.9%		
08/07/2017	1.003	1.048	1.056	1.032	1.059	1.044	1.027	1.056	8.325	1.059	1.048	1.0395714	-0.8%		
09/07/2017	0.971	1.003	1.015	1.015	1.014	1.009	1.001	1.01	8.038	1.015	1.003	1.005	0.2%		
10/07/2017	0.623	0.665	0.666	0.66	0.665	0.662	0.648	0.661	5.25	0.666	0.665	0.655	-1.5%		
11/07/2017	0.316	0.345	0.342	0.341	0.34	0.341	0.334	0.337	2.696	0.345	0.345	0.3358571	-2.7%		
12/07/2017	1.091	1.132	1.139	1.124	1.14	1.128	1.114	1.14	9.008	1.14	1.132	1.1251429	-0.6%		
13/07/2017	0.561	0.595	0.594	0.589	0.593	0.591	0.579	0.59	4.692	0.595	0.595	0.5852857	-1.7%		
14/07/2017	0.724	0.776	0.76	0.76	0.757	0.754	0.751	0.757	6.039	0.776	0.776	0.7518571	-3.2%		
15/07/2017	0.405	0.444	0.439	0.437	0.436	0.437	0.429	0.433	3.46	0.444	0.444	0.4308571	-3.1%		
16/07/2017	0.586	0.62	0.626	0.628	0.622	0.624	0.616	0.618	4.94	0.628	0.62	0.6171429	-0.5%		
17/07/2017	1.309	1.339	1.35	1.329	1.357	1.336	1.328	1.365	10.713	1.365	1.339	1.3391429	0.0%		
18/07/2017	1.242	1.274	1.282	1.273	1.29	1.271	1.264	1.293	10.189	1.293	1.274	1.2735714	0.0%		
19/07/2017	0.299	0.324	0.325	0.322	0.323	0.322	0.315	0.32	2.55	0.325	0.324	0.318	-1.9%		
20/07/2017	0.86	0.913	0.895	0.897	0.893	0.889	0.884	0.896	7.127	0.913	0.913	0.8877143	-2.8%		
21/07/2017	0.425	0.464	0.455	0.455	0.453	0.453	0.445	0.45	3.6	0.464	0.464	0.448	-3.6%		
22/07/2017	0.679	0.713	0.715	0.707	0.718	0.713	0.696	0.715	5.656	0.718	0.713	0.7061429	-1.0%		
23/07/2017	0.892	0.929	0.926	0.918	0.926	0.918	0.91	0.926	7.345	0.929	0.929	0.9165714	-1.4%		
24/07/2017	0.493	0.527	0.525	0.525	0.521	0.523	0.515	0.52	4.149	0.527	0.527	0.5174286	-1.8%		
25/07/2017	1.017	1.062	1.053	1.053	1.054	1.045	1.042	1.056	8.382	1.062	1.062	1.0457143	-1.6%		
26/07/2017	0.563	0.608	0.595	0.597	0.588	0.592	0.584	0.589	4.716	0.608	0.608	0.5868571	-3.6%		
27/07/2017	0.708	0.756	0.743	0.744	0.74	0.739	0.734	0.738	5.902	0.756	0.756	0.7351429	-2.8%		
28/07/2017	0.376	0.409	0.407	0.4	0.405	0.404	0.393	0.4	3.194	0.409	0.409	0.3978571	-2.8%		
29/07/2017	0.627	0.681	0.671	0.666	0.669	0.667	0.656	0.664	5.301	0.681	0.681	0.66	-3.2%		
30/07/2017	0.803	0.845	0.841	0.833	0.838	0.832	0.823	0.837	6.652	0.845	0.845	0.8295714	-1.9%		
31/07/2017	0.864	0.897	0.896	0.89	0.897	0.886	0.882	0.897	7.109	0.897	0.897	0.8874286	-1.1%		
Energy	24.171	25.364	25.336	25.175	25.329	25.136	24.873	25.29	200.674 kWh	(kWh)	24.467	24.156857	-1.3%		

Table 1 - Electrical energy captured by PVT and PV collectors during July 2017

Generation Increase With PV-T					
	2015	2016	2017	2018	2019
January		-8.7%	-7.4%	-6.6%	-8.3%
February		-4.0%	-3.6%	-4.0%	-5.9%
March		-2.1%	-4.1%	-2.0%	-7.2%
April		-0.8%	-4.7%	-4.9%	-4.6%
May		0.6%	0.8%	-4.0%	
June		0.8%	0.1%	0.1%	
July		0.4%	-1.3%	-0.7%	
August		-1.9%	-3.4%	-3.1%	
September	-8.4%	-4.7%	-5.6%	-7.7%	
October	-6.1%	-3.6%	-5.0%	-6.0%	
November	-7.3%	-4.8%	-8.0%	-10.3%	
December	-2.9%	-7.6%	-12.7%	-7.5%	
Year	-6.6%	-1.6%	-3.2%	-3.4%	-5.9%

Table 2 - Monthly percentage increase of average PVT output vs equivalent PV

One way to increase the heat transferred to the EEB is to increase the temperature of the PVT collectors, perhaps by using glazed collectors, although this would naturally reduce the electrical output still further. In the design of seasonal storage systems of this kind, there is clearly a trade-off between thermal output and electrical output; but if system designers can find a way to increase the rate of heat transfer into the EEB during summer without increasing the temperature of the fluid in the solar loop, this will increase both types of energy capture. One means of doing this might be to use phase change materials to extract more heat from the borehole heat exchangers when it is available at high temperature (typically around midday) and then release this heat into the EEB after the temperature of the PVT collectors has fallen as the solar energy input reduces (Yang et al., 2019).

Conclusions and implications for the sustainable development goals

Solar PVT technology has a significant advantage over conventional solar PV in allowing the collection of thermal energy as well as electrical energy from the same collector area, at the cost of some additional system complexity. Those considering the operation of solar PVT often assume that extracting heat by forced cooling will enhance the electrical output of the device compared to a similar PV collector, but this paper has shown that under certain conditions this is not the case. The electrical output may in fact reduce, due to the presence of warm coolant and thermal insulation, which combine to maintain a higher temperature of the semiconductor material. However, this paper has shown that in hot summer conditions forced cooling has a small advantage over cooling by natural convection that is typical of PV installations. In the temperate conditions of the UK, the differences are small and in the system described here amounted to an overall reduction in the annual electrical output of PVT compared to PV of less than 4%.

However, in the higher temperature conditions common in many developing countries, the benefits of solar PVT technology may be much more significant since the PV temperature reduction through forced cooling may be significant compared to natural convection. Solar PVT technology can therefore contribute to meeting sustainable development goal (SDG) 7, which is the provision of clean and affordable energy, because it delivers two types of renewable energy - electrical and thermal, and it enhances the delivery of the former in hot conditions. The use of solar PV has brought dramatic improvements to the lives of millions in remote off-grid locations in developing countries, but the additional provision of low temperature renewable heat using PVT could bring additional benefits as well as increasing the electrical energy available to these communities. Such benefits are unlikely to include space heating (although at high altitudes, this might be valuable), but may be very useful for domestic hot water and water treatment processes such as solar distillation or pasteurisation. One can imagine a solar water purification device powered by one or more PVT collectors that provides electrical energy for UV treatment and thermal energy for pasteurisation. The availability of electrical energy allows the option of electrical heating that could supplement the thermal output of the PVT and allow the residence time for pasteurisation to reduce. If a working prototype can be demonstrated, solar PVT will be shown to have contributed to meeting both SDG7 and SDG6, which is to ensure availability and sustainable management of water and sanitation for all.

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BIOMASS ENERGY POTENTIAL IN RURAL COMMUNITIES

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ABSTRACT

Brazil has a great potential to produce bioenergy in rural areas due to the availability of renewable sources. This study presents guidelines for rural communities to become sustainable with the implantation of biogas plants by harnessing the existing biomass in the site. The proposal is to presenting an attractive alternative for the government and entrepreneurs, under both financially and environmentally aspects, as they offer reduced electricity grid costs and the commercialization of carbon credits. The rural settlement Estrela da Ilha was used as a case. The potential to produce electric energy with the use of biodigestor coupled to the motor generator in the conversion of existing biomass was evaluated, considering the economic viability.

Keyword: Bioenergy. Rural communities. Sustainable model. Distributed Generation.

1. INTRODUCTION

Access to electric power brings comfort and well-being to citizens, through the use of lighting and electrical and electronic equipment in general. However, the main differential of access to this asset is the great improvement in socioeconomic development, since it allows workers to increase their economic and productivity gains through the use of equipment that improves their performance at work. Both examples of the impact of the use of electric energy are directly related to quality of life and human development.

In Brazil, approximately 1 million families still live without electricity, which represents 0.48% of the total population (Dassie, 2016). Although this percentage is low, almost 82% of the families that do not have access to electric energy live in rural areas. And it is precisely in this

environment that bioenergy can play an important role in the universalization of this service, with the use of biomass in the generation of electric energy.

Biomass is a primary energy obtained from agricultural, forestry and animal crop and waste, solid waste and organic and residential effluents, including sewage treatment plants (MAO et al., 2015). Biomass is one of the most important energy sources in the world's electricity production, given its abundance and capacity for renewal, in addition to its environmental advantage when compared to fossil fuels (Chen et al., 2014).

Although Brazil has a matrix of electricity generation predominantly composed of renewable sources (approximately 87% of all production), biomass contributes only for 7.3% (ALMEIDA et al., 2017). There are several technologies for the conversion of biomass into electricity. In rural areas, biodigesters coupled to motor-generator set are the most used, given their simplicity of operation, maintenance and functionality. Given this scenario, this study proposes to work on the concept of bioenergy as a sustainable solution for rural communities, through the use of existing biomass and the cultivation of energy crops in the production of electric energy. Proposals are presented to encourage public policies to increase the supply of bioenergy in rural areas, particularly in small farms.

2. BIOMASS AS ENERGY SOURCE

One of the technologies most used for the use of biomass in the electric power generation is anaerobic digestion, through biodigesters, for the production of biogas (GONZAGA et al., 2016). The digestion process transforms complex organic compounds into simpler substances as methane (CH_4), with a representability of 60% to 80% in the total composition of the gas, the carbon dioxide (CO_2), between 20% to 40%, and other gases in a much smaller proportion (around 1%), such as nitrogen (N), hydrogen (H) and sulfuric gas (H_2S) (FERNANDES et al., 2015). Biogas can be used directly as fuel in Otto cycle internal combustion engines that use fossil fuels, with some adjustments. This motor coupled to a generator produces the desired electrical energy.

In addition to the class of biomass used in the process, other characteristics influence the anaerobic digestion process, such as temperature, pH, water retention time and solid retention time, physical, chemical and biological accelerators. of temperature controllers and biomass mixers, and computer control systems (KARIYAMA et al., 2018).

The degradation of the biomass occurs in the anaerobic digesters (biodigestors) as already mentioned. There are conventional models that are built very simply, can meet the demand of the biomass digestion producing the biogas that is collected by the gasometer and used mainly for the generation of electric and / or thermal energy, and the biofertilizer is the other by- widely used as organic fertilizer. Among the best known are: "Indian model" floating bell digester, fixed model digester "Chinese model" and the tubular digester with inflatable blanket "Canadian model" (NESHAT et al., 2017).

Reactors are more complex biodigestors, provide higher efficiency and better efficiency compared to traditional ones, but the costs of implementation, maintenance and operation are relevant factors for decision making. Among the several existing reactors, the Anaerobic Sludge Blanket (UASB), suitable for digestion of urban waste and sewage treatment plants, and the Continuous Stirred Tank Reactor (CSTR) are the most used for anaerobic digestion for biogas production.), inducted for the digestion of vegetable and animal residues, energy crops and even agroindustrial (BOE K. et al., 2006; RICO et al., 2015; NESHAT et al., 2017).

3. SUSTAINABLE COMMUNITY

Brazil stands out for its territorial and climatic conditions as a great potential producer of bioenergy, from the use of agricultural, animal and agroindustrial residues, to the planting of energy crops without competing with traditional agriculture, besides the use of municipal solid waste and sewage treatment plants, all of which are geared towards the production of biogas.

In order to encourage sustainability in rural areas, the Brazilian government has prepared Normative Resolution 687 of November 2015 (NR687/2015) released by the National Electric Energy Agency (ANEEL), which establishes rules and criteria for rural properties to produce their own energy. The NR687 defines mini generation (installed power above 75 kW and less than or equal to 5 MW) and micro generation (installed capacity less than or equal to 75 kW). The energy produced is used by the property and its surplus is exported to the distribution grid and converted into credits in the amount of active energy to be consumed for a period of 60 months.

In addition to the generation of electric energy, biogas can be applied in other areas, mainly through its purification, by obtaining biomethane ($\text{CH}_4 > 94\%$ in its composition), it

becomes a product capable of replacing natural gas and being used as biofuel, in addition to the production of pure hydrogen.

The Brazilian government in 2018 officially presented a new program that aims at the applicability of biomethane in the national scenario and highlights its importance called *RenovaBio*.

The program aims to expand the sustainable production of biofuels in a socially and environmentally sustainable way in Brazil by stimulating competition between biofuels themselves (including the development of new ones, such as biomethane and biokerosene), through the creation of instruments to price biofuels. relation to energy efficiency and gas emissions, valuing sustainable production (MILANEZ et al., 2018).

RenovaBio seeks to harmonize the monitoring of national emission reduction targets for the Brazilian energy matrix with the expansion of biofuel production. For this, the creation of the decarbonisation credit (CBio), which will become a financial asset, tradable in a stock exchange, issued by the producer of biofuels at the moment of commercialization is desired. Distributors will have to meet the targets set by CBios ownership in their portfolios.

The Brazilian government encourages the use of renewable technologies as already mentioned, however this incentive only favours effectively after the production of bioenergy, that is, even if a project is profitable it may not leave the paper due to lack of initial financial resources. A credit line for the deployment of bioenergy plants may be the alternative to adequately meet the demand of the site by setting the best scenario for such production, and thereby create a relationship between the local residents with the government and with the energy concessionaires, allowing a reduction of the costs with the electric network and greater benefit from the reality of the community.

The financial value needed to set up a power plant should be proportional to the energy potential of the community, that is, through a well-founded project, it is possible to obtain guarantees for the government of how much the site is capable of producing bioenergy.

Thus, this article presents the feasibility of elaborating a scale that shows the energy potential of the rural community and classifies it in terms of financial and sustainable benefits. To do so, a methodological procedure is applied that uses as steps biomass mapping available at the site, evaluation of the types of biomass conversion technology in bioenergy, creation of new scenarios using several energy crops and, finally, economic viability of project execution.

This methodology can be used not only for the government to evaluate the viability of the project, but also for investors interested in the commercialization of carbon credits and in the biomethane credits of the RenovaBio program.

4. CONVERSION OF BIOMASS TO BIOENERGY

From the survey of all available biomass in the settlement, the study uses RETScreen software, a mathematical model capable of simulating technical and economic efficiency, as well as a continuous analysis of energy performance using renewable technologies in bioenergy generation.

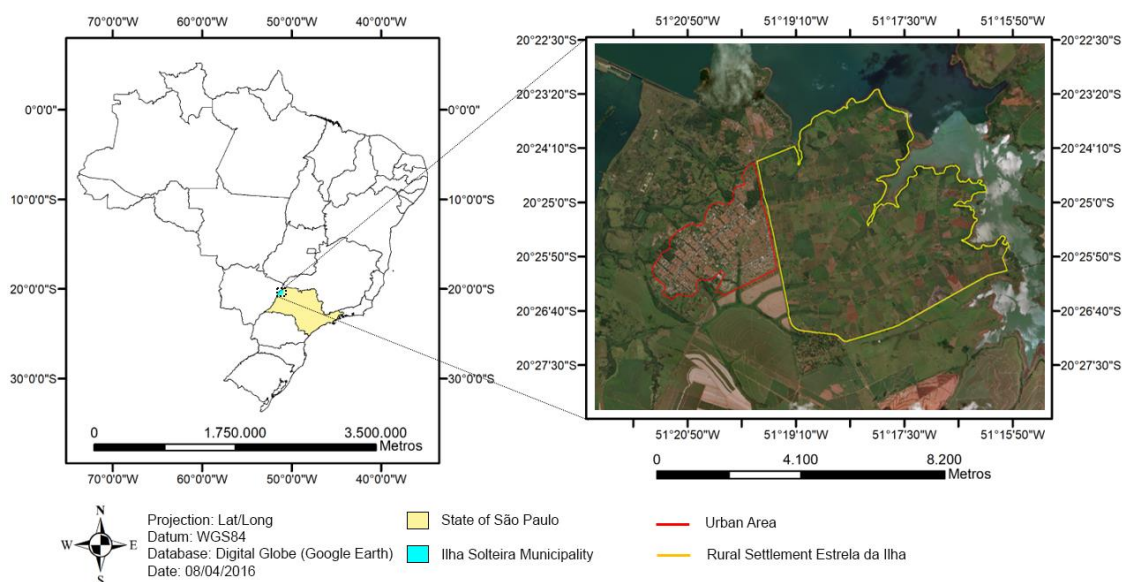
RETScreen (Clean Energy Management) Software is a free program developed by the Government of Canada, supported by an international network of industry, government and academic experts. Major partners include NASA (National Aeronautics and Space Administration), REEEP (Renewable Energy and Energy Efficiency Partnership), IESO (Independent Electricity System Operator), UNEP (United Nations Environment Program) and GEF Global Environment Facility). By 2014 there were more than 400,000 users around the world, with the most widely used renewable energy project analysis software.

This software is a decision support tool, can be used universally to evaluate energy production, life cycle costs, reduction of greenhouse gas emissions, and financial and risk analyzes for various types of projects energy efficiency and renewable energy technologies (CANADÁ, 2015).

4.1 PROFILE OF THE AREA CONSIDERED

The case study was developed in the Estrela da Ilha rural settlement, in the municipality of Ilha Solteira (SP), represented in Figure 1. The municipality is located in the extreme northwest of the state of São Paulo, it borders the state of Mato Grosso do Sul and its geographical location has the latitude coordinates 20°38'44" and longitude 51°06'35" (Municipal Plan for Sustainable Rural Development, 2010-2013).

Figure 1 – Rural settlement Estrela da Ilha.



Source: Prepared by the author.

Information on the characterization of the settlement was obtained through official documents provided by COATER, provider of INCRA (Brazilian government agency responsible for colonization and agrarian reform) for research purposes. The settlement Estrela da Ilha has an extension of 29.64 km² and its division is characterized in 210 lots, being 182 plots with 140.000 m² and 28 plots with 35.000 m². The main activities carried out are the cultivation of perennial and annual crops and the production of animals, mainly of cattle destined to milk practice.

At the beginning of 2016, COATER carried out, through a request from INCRA, the application of the socioeconomic diagnosis in each batch inserted in the regional of Andradina, in order to gather general data of the lot, addressing issues from family to the infrastructure of each productive unit.

The obtained data were counted for the calculation of biomass generation. Information on the energy potential for conversion into electricity is summarized in: the number of existing animals (cattle, pigs and birds); the use of the occupied land areas, in hectares, distributed in

pasture areas, permanent crops, annual crops, horticulture and reforestation.

Due to the "in situ" fact, the pasture (with 63.84% of the total settlement area) can not be accounted for due to the fact that the herds used in the feed and there is not enough material available for the process. Reforestation (0.25% of the total settlement area) is also not used because its use in this process occurs through the burning of thermoelectric plants, thus, the use of biodigesters.

For the mapping of the biomass present in the Star Island settlement, the biomass sources in the area were divided into two: animal sources and plant sources. Table 1 discriminates the types of animals and the quantity in the settlement

Table 1 – Number of animals in the settlement Estrela da Ilha, 2016.

Type of animals	Numbers of animals (head)
Cattle	3,357
Pig	664
Bird	10,527
Total	14,548

Source: Prepared by the author.

In relation to the available biomass of vegetables, it is subdivided into permanent crops (orange, lemon, papaya, avocado, coconut, mango, jackfruit, mandarin, banana, acerola, coffee, annatto, sugarcane, among others to a lesser extent), annual crops (sorghum, beans, sweet potatoes, pumpkins, eggplants, jiló, gherkins, cucumbers, peppers, okra, cassava, pods and vegetables), and corn stands out because it is the culture on a larger scale of local production due its relevance as one of the main products marketed in the settlement and also in the preparation of the silo for the animals.

According to Favarin (2017), the generation of residues in agricultural production varies from each activity, crop, humidity, temperature, seasonality, soil, organic compounds, among other factors. In an estimate of the crops found in the settlement, with a moisture content of 15% (ideal for the biodigester), the study adopts the relation of 5 tons of annual residues per hectare of planted area.

Table 2 lists the types and quantity of mapped vegetables in the settlement and the amount of waste estimated in tonnes per year.

Table 2 – Number of vegetables in the settlement Estrela da Ilha, 2016.

Type of vegetables	Number of plants (hectare)	Waste (ton.year ⁻¹)
Corn	78.26	391.30
Permanent crops	126.12	630.58
Annual crops	134.73	673.65
Total	339.11	1.695.53

Source: Prepared by the author.

The data cover a total area of 339.11 hectares subdivided between corn production, permanent crops and annual crops with an annual production of 1,695.53 tonnes of waste.

4.2 SIMULATION CALCULATION

In the case of the technology proposed by this study, the software calculates the biogas production according to the quantity of each type of material to be processed in the biodigester. Table 3 shows the biomass conversion in biogas calculated by the software, with the dry matter indices (%), biogas production factor (m³.kg⁻¹), annual biogas production (m³) and methane concentration (%).

To estimate the amount of residues produced daily by animals, the study was based on data provided by Sganzerla (1983), Colatto et al. (2011) and Kunz et al. (2006). All indicate the amount of 10 kg of manure by cattle, 2.25 kg by pigs and 0.18 kg by birds.

Table 3 – Estimated total biogas production in the settlement.

Unity	Avareg e weight per unit (kg)	Amou nt	Dry matter (%)	Dry matter – volatile solids (%)	Biogas productio n factor (m ³ .kg)	Productio n of biogas - annual (m ³)	Content of methane (volume %)
Dairy cattle	10	3,357	8.0%	100.0%	0.33	24,813	60%
Pig	2.25	664	7.0%	100.0%	0.69	1,498	68%
Birds	0.18	10,527	32.0%	71.5%	0.54	5,341	69%
Corn storage	1,000	391	27.5%	90.0%	0.58	55,644	53%
Fruit and vegetable waste	1,000	1,304	12.5%	85.0%	0.50	69,275	63%
Total		16,243				156,571	58.8%

Source: RETScreen, 2018. Adapted the author.

The total biogas value is 156,571 m³.year⁻¹ and the methane concentration in the compound is 58.8%. The methane is the gas responsible for the quality of the compound, in the literature, 60-80% is ideal for the proper functioning of the motor generator, otherwise loses efficiency in the production of electric energy.

With the calculated value of the biogas, Table 4 contemplates all the information used by the software, with its respective steps. Information on the biodigestor such as sizing, model and costs was made available by the company RECOLAST through a consultancy for academic purposes and, in relation to the information on the motor generator was made available by the company ER-BR also through a consultancy for academic purposes, both are conceptualized in the market

Table 4 – Main parameters used by software RETScreen.

RETScreen		Main parameters	
Start	Information about the project	Project type	Production of eletricity
		Technology	Reciprocal mtor
		Capacity factor	7.971,6 hours (91%)
		Calorific reference power	PCI
		Location of climate data	Ilha Solteira/SP
Energy model	Proposed case electricity system	Method – fuel selection	Single fuel
		Type of fuel	Biogás
		Fuel price	R\$ 0,00/m ³
		Reciprocal motor power	50 kW
		Motogenerator	R\$ 1.600,00/kW
Cost analysis	Upfront costs	Biodigestoer (720m ³)	R\$ 41.000,00
		Biomass and motogenerator	R\$ 25.000,00
		Annual operating and maintenance cost	User defined
	Periodic costs	Reset the motogenerator	R\$ 80.000,00 every 7 years
		Replacement of the biodigestor canvas	RS 23.000,00 every 11 years
Financial analysis	General	Inflation rate	2%
		Discont rate	9%
		Life of the project	20 yeras

Source: Prepared by the author.

When analyzing the feasibility of setting up a power plant with the use of available biomass in the Estrela da Ilha rural settlement, the RETScreen software made it possible to visualize a scenario with the costs of the implementation, operation and maintenance, replacement of equipment, generation revenues the financial viability of the entire project.

The project was estimated for a period of 20 years, with an initial cost of £25,000.00 (motogenerator, biodigestor and construction of the shelter of the biomass pool and storage), annual costs with operation and maintenance of £950.00 and £2,300.00 of debt for a period of 15 years and cost with replacement of the motor generator of £16,500.00 every seven years and the canvas of the biodigestor of £4,700.00 every 11 years.

With this system, an electric power production of 399 MWh.year⁻¹ is estimated at a cost of £48 per MWh. Revenue from the production of electric energy was £19,250.00 with its export to the grid, with a GHG emission reduction of 17 tCO₂.year⁻¹ (equivalent to a reduction of 3.1 vehicles).

Through the production of energy, the settlement can be framed in the shared generation, that is to say, it is characterized by the meeting of consumers within the same concession area, where there is a consumer unit with microgeneration or distributed mini generation and the surplus energy is compensated, according to with RN687/2015 provided by ANEEL. By estimating and simulating the potential of the settlement to generate electricity, residents can organize themselves to deploy biodigesters strategically for access and benefit to all.

Regarding financial feasibility, the project obtained a return on equity in seven months, ie, initial investment cost would be amortized in this period. The internal rate of return on equity was 185% and net present value in the amount of £150,000.00 and the cost-benefit ratio of 17.7.

The cost of electric energy consumption in the entire settlement was estimated by the simulator on the site of ELEKTRO (Electric Power utility of São Paulo State) for the month of September 2018 in the amount of £79,000.00 (taxes included). Through revenue from energy production, it can achieve a 24.38% reduction in energy costs throughout the settlement

In conclusion, according to the software application analysis, the implementation of the power generation system in the Estrela da Ilha rural settlement proved to be efficient with the production of electricity through the use of available biomass, with a recovery of initial

investments within a period of seven months from own resources. However, it is worth mentioning that the costs of transporting and collecting the biomass to the proposed place for the installation of the power plant were not accounted for.

Finally, in addition to simulating the energy potential of the Estrela do Ilha rural settlement, the study allows creating new scenarios with the planting of energy crops, in order to obtain an increase in bioenergy production of the place through the use of energy mapping, optimizing the area existing.

An example is the planting of elephant grass as an energy crop, destined for the production of biogas. Elephant grass produces $49.75 \text{ t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ dry matter. If you consider only 10% of the pasture land in the Ilha da Estrela settlement, it equals 189.24 hectares, it will produce $9,414.69 \text{ tons}\cdot\text{yr}^{-1}$ (NEIVA, 2016). When simulating this biomass in the conversion to biogas, it is estimated a production of $1,694,644 \text{ m}^3$. This volume represents more than 10 times the value of biogas production with available biomass.

5. CONCLUSIONS

Rural communities can develop a sustainable model, as in the Estrela da Ilha rural settlement case, from shared generation as stated in the NR 867/2015 from ANEEL. Energy production can be increased from energy crops without affecting current activities. The RenovaBio program which considers purification and commercialization of biomethane as biofuel can also be followed.

Initial costs with the plant's implementation can be a challenge, especially for residents of the Estrela da Ilha rural settlement due to their low average income. Governmental support along with private investors is the key to solve this drawback.

Investors can benefit from the reduction of electricity grid costs and the trade of carbon credits and CBios by the new Brazilian RenovaBio program for biofuels.

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Integrating solar to ground seasonal heat storage for the small domestic heating sector in the UK: Experiments from a research prototype

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Abstract

Accessing to clean and affordable energy is a challenge that most of the countries must deal with. That is why the United Nations has set this as part of the sustainable development goals for 2030. The integration of renewable and more efficient technologies for domestic heating applications can notably contribute to minimise the global carbon emissions and increase the global ratio of energy efficiency. In this paper, an experimental analysis of the energy fluxes involved in a solar assisted ground source heat pump system is conducted. The system is composed of 16 shallow boreholes of 1.5 metres deep. Data collected for 19 months show that, even though the ground storage system is conceived to be insulated, there is a little heat that is extracted from the soil in order to supply the heat demands. An analysis of the potential of widely using this technology in England is briefly discussed. This affordable technology could compete with conventional electric heating and using a smart control, it can be competitive with gas heating. If this is widely applied in the new domestic homes, a favourable impact towards clean and affordable energy can be reached.

1. Introduction

During the last decade, policies aiming to reduce energy consumption have contributed to slowing the growth of global energy demand. However, 30% growth in energy demand is still expected until 2040 [1]. This is the equivalent of adding another China and India to the current world energy demand [1]. Nevertheless, the scenario is not so discouraging as great progress has been made to date. For instance, the global energy efficiency has increased as more renewable energy sources have been added as sources of primary energy. Also, the prices of photovoltaic panels have been reduced by 70% from 2010 to 2016 [1]. Unfortunately, many of these changes and developments have not been evident globally, but to specific economic sectors. Therefore, the global energy problem has become one of the United Nations Sustainable Development Goals (SDGs) in order not only to reduce the consumption of fossil fuels but also to guarantee access to clean energy globally [2]. In fact, one of the targets of the SDG 7 (Clean and affordable energy) is to double the overall rate of improvement in energy efficiency until 2030 [2]. It is important to mention that the buildings sector is one of the main consumers of global energy, being responsible for 40% of the total energy consumption [3]. For this reason, in the last decades, standards have been implemented for more efficient construction in order to avoid excessive growth in the energy demand of buildings [4]. Yet, these types of measures and standards have focused mainly on large buildings without considering that the small residential sector is also a sector of high energy demand with a big potential for energy savings [5]. Nowadays, with the reduction of prices in renewable technologies and the constant improvement in construction methods, it is possible that efficient renewable technologies are more accessible for the small domestic sector. The efficient design is very important since it allows to reduce the annual and peak thermal loads and thus require smaller systems capable of supplying the

energy demands. One of these technologies, which has shown great potential in recent years, is geothermal energy for space conditioning [6]. Within the applications of this type of technology, closed ground source heat pump (GSHP) systems are the most used [7]. In heating systems, a GSHP has advantages over a conventional (air source) heat pump, mainly because the ground as a heat source has a higher temperature than the air in winter, which increases the coefficient of performance (COP) of the heat pump [8]. GSHPs are classified according to the type of geothermal heat exchanger (GHE) used. Horizontal heat exchanger systems are typically installed between 1.5 and 2 meters deep and pipe arrangements are placed on a large surface of land [9]. On the other hand, vertical heat exchanger systems are composed of double or single U-tube boreholes, installed at depths between 40 and 300 meters [10]. The limitation for the large-scale use of vertical systems is the high cost of installing the GHEs. In horizontal systems, it is required to remove large volumes of soil, while in vertical systems, robust machinery is needed for drilling deep into the ground [11]. Nevertheless, as previously mentioned, the improvements in building construction methods plus the use of more efficient technologies such as solar assisted ground source heat pumps (SAGSHP) systems or dual source heat pumps systems, has allowed reducing the sizing of the GHEs, with shallow boreholes appearing as an alternative [12]. Even though shallow boreholes are affected by the seasonal and short-term temperature variations in the shallow soil [13], this concept presents an advantage since the use of shallow systems makes this type of technology more competitive due to the considerable cost reduction during the borehole drilling. In fact, in shallow systems (up to 5 meters deep), drilling can be done with a fence post auger [14]. An example of this is the concept of the solar house developed by Caplin Homes, which uses an array of shallow boreholes assisted by solar energy to store heat within the foundations of a dwelling. The use of solar energy allows to increase the temperature of the ground, and this also contributes to the reduction of the size of the vertical boreholes [14]. This concept is profitable when applied in new buildings where the machinery to build the foundations of the buildings is on site, which minimizes the drilling cost. If the United Kingdom is taken as an example, according to the Ministry of Housing, Communities and Local Governments, 160000 homes are built in England each year [15]. Considering that the domestic sector is responsible for 28% of total UK energy consumption and that 80% of that consumption is due to heating [16], it can be predicted that there is a lot of potential for the implementation of the technology of shallow GSHP systems. This can contribute significantly to the SDG 7 and help to meet the goals of the United Nations. In this context, the objective of this paper is to present the first experimental results of a SAGSHP system that uses shallow boreholes for domestic heating of a small dwelling. These results will be presented in terms of the energy fluxes of the system. Likewise, this research aims to give a brief estimation of the potential energy savings that this type of systems can provide in the small domestic sector and in this way contribute to the United Nations SDG 7.

2. Methodology

The methodology of this research is based on the study of the behaviour of an experimental system installed in a Victorian house in Leicester, UK. The 75 m² house belongs to De Montfort University and is occasionally occupied by students of forensic science for mock-up crime scenes. Therefore, the house has space heating demands, but not domestic hot water (DHW) demands. Although the house is not occupied, for reasons of research, an indoor set point temperature of 18°C was fixed for the whole period of analysis. The house is adjacent to similar houses on both sides and the external walls are solid brick without insulation. The roof is sloped

and insulated, and the windows are double-glazing with PVC frames. Based on this, it can be said that the house has higher thermal loads than those of a low-energy house. The house is heated by a SAGSHP system that provides heat through underfloor heating on the ground floor. The house also has the old heating system (gas boiler and radiators) as back up.

2.1. Description of the solar assisted ground source heat pump system

The SAGSHP system consists of 16 shallow vertical boreholes of 1.5 metres depth (single U tube) connected in series and assisted by 7 solar photovoltaic-thermal collectors (PVT). The ground heat exchanger (GHE) is connected to a GSHP that provides heat to the house through an underfloor heating system. The system also provides heat to a 120-litre tank for DHW needs, although this is not connected to the hot taps. The GHE is installed in a volume of soil called an ‘earth energy bank’ (EEB). The EEB should ideally be located within the foundations of the buildings, however as the current research is based on a retrofit installation, the EEB was installed outside the building within an area equivalent to the footprint of the dwelling. Likewise, the EEB has a top and sides layers of insulation (20 cm on top and 10 cm on sides) and an extra layer of concrete in the sides (10 cm). This might be equivalent to having the GHE in the foundations of the house. Figure 1 shows a schematic of the experimental system of the present study. As seen in the figure, the system consists mainly of three fluid loops. The solar loop, the GHE loop, and the heating loop. The solar and GHE loops use glycol (30% by volume) as working fluid. When the temperature at the outlet of the PVT collectors is at least 7 K higher than the EEB (ground) temperature, the solar loop pump is activated. The heat gained through the PVT collectors is transferred to the GHE loop through a heat exchanger. If the heat pump is not in operation, the fluid recirculates and continues with the recharge of the EEB, provided that the temperature difference between the EEB and the outlet of the PVT allows it. If the heat pump is in operation, the fluid exchanges heat with the heat pump to meet the heating demands. When the outlet temperature of the PVT collectors falls below the EEB temperature, the solar loop pump is deactivated. If there is a demand for heating, the heat pump will extract heat from the EEB. In this way, the EEB will lose stored heat that must be recharged when there is again solar energy availability.

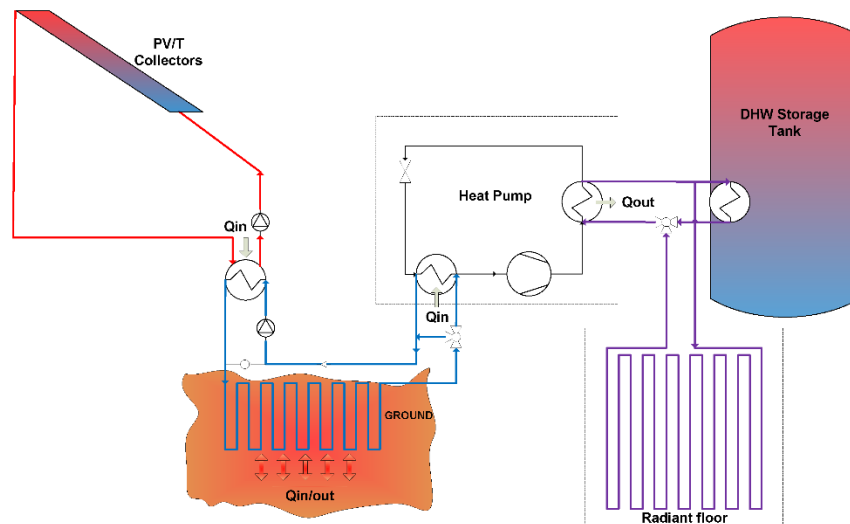


Figure 1. Experimental SAGSHP schematic

2.2. Heat fluxes calculation

To calculate the heat fluxes that are involved in the experimental system, the EEB is taken as the control volume since this is the intermediate sub-system between the solar sub-system and the heat pump. Figure 2 shows the heat fluxes and boundaries of the EEB. In the figure, the input heat fluxes in the system are the heat coming from the solar collectors (Q_{solar}) and the heat of gained by conduction through the bottom of the EEB (Q_{geo}). Q_{geo} exists if the temperature of the bottom of the EEB (2.75 m) is lower than the natural temperature of the soil at a depth undisturbed by the GHE that numerically was found to be at 3.75 m. On the other hand, the output heat fluxes are the heat demanded by the heat pump (Q_{eva}) and the heat that is lost to the surrounding soil from the bottom of the EEB (Q_{loss}). Like Q_{geo} , Q_{loss} exists if the temperature of the bottom of the EEB is higher than the natural temperature of the ground at 3.75m.

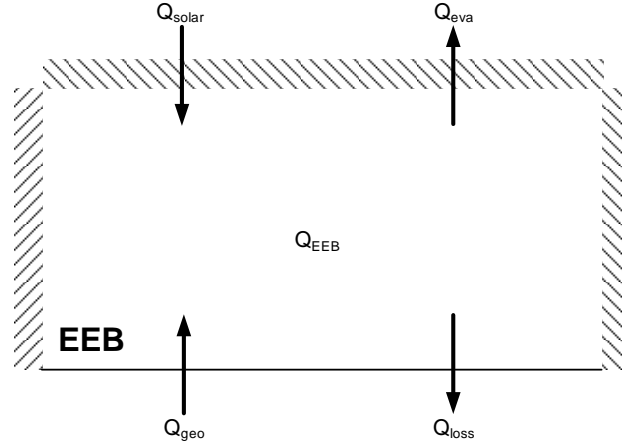


Figure 2. EEB boundaries and heat fluxes involved

Equation 1 shows the energy balance of the EEB which is the basic calculation of the thermal behaviour of the shallow GHE.

$$Q_{solar} + Q_{geo} - Q_{eva} - Q_{loss} = Q_{EEB} \quad (1)$$

The solar and evaporator heat fluxes were determined by Equations 2 and 3 respectively. Both the inlet and outlet temperatures of the collectors and GHE and the mass flows were measured experimentally. The data were measured at 15-minute intervals and averaged to hourly data. The data used for this study corresponds to the period from 04/06/2016 to 12/31/2017.

$$Q_{solar} = \dot{m}_{ghe} \times c_p \times (T_{in_{solar}} - T_{out_{solar}}) \quad (2)$$

$$Q_{eva} = \dot{m}_{ghe} \times c_p \times (T_{in_{eva}} - T_{out_{eva}}) \quad (3)$$

In Equation 2, $T_{in_{solar}}$ and $T_{out_{solar}}$ represent the inlet and outlet temperature of the heat exchanger between the GHE and the solar collectors on the GHE side. Similarly, in Equation 3, $T_{in_{eva}}$ and $T_{out_{eva}}$ are the inlet and outlet temperature of the heat exchanger between the GHE and the heat pump on the GHE side. In the same way, the heat fluxes with the surroundings (Q_{geo} and Q_{loss}) were determined by the Fourier law that estimates the heat flux by conduction in a solid medium [17].

To assess the efficiency of the GSHP, the monthly seasonal performance factor (SPF) was determined. For this, Equation 4 was used, where t_o and t_f are the initial and final time of each month evaluated.

$$SPF = \int_{t_o}^{t_f} \frac{Q_{eva} + W_{ele}}{W_{ele}} dt \quad (4)$$

As shown in Equation 1, the heat sources of the EEB and consequently for the heat pump come from solar energy (Q_{solar}) or the surrounding soil (Q_{geo}). For this reason, the total amount of solar and geothermal heat that was used to satisfy heating demands was also determined during the total study period of the energy balance. For this, Equations 5 and 6 were used.

$$Q_{solar_{tot}} = \int_{t_o}^{t_f} Q_{solar} dt \quad (5)$$

$$Q_{geo_{tot}} = \int_{t_o}^{t_f} Q_{geo} dt \quad (6)$$

3. Results

3.1. Experimental data analysis

The experimental system was analysed from hourly data collected for 19 months. The data collected was previously treated in order to discard any outliers and all the data analysis and calculations were done in Matlab. From the data analysed, it can be highlighted that, despite the actual quantity of heat that shallow boreholes can extract due to their shallow depth, the increase in the EEB by the solar energy injection allows the system to extract more heat in winter due to a higher temperature difference. However, as the heating requirements in winter are high, the EEB cool down very fast reducing the temperature of the EEB and thus reducing the heat pump COP. Nonetheless, this issue can be minimised in low-energy homes where heating loads are low, and a shallow geothermal system could easily satisfy the heating demands [14]. Regarding the monthly system performance, Figure 3 shows the energy balance of the EEB. It can be noticed that during summer months, most of the actual solar energy gained is transferred to the EEB. If there are no heating demands in summer (for DHW), the solar energy will be stored and if the EEB temperature increases, the energy losses through the bottom increase as well. This is evident when comparing the first and the second month of storage. For instance, in June 2016, there are almost no energy losses, that is because the temperature difference between the EEB and the surrounding soil is very low. However, in July and August 2016, as the EEB ground temperature increases, the temperature difference with the surrounding soil increases too, and consequently, more energy losses occur. Figure 3 also shows that whenever there is solar energy available but also a heat demand in the evaporator, is the solar system the one that supplies the evaporator. This particular mode of operation should be avoided as there is a risk of having too high fluid entering temperature to the heat pump and the system could shut down for protection.

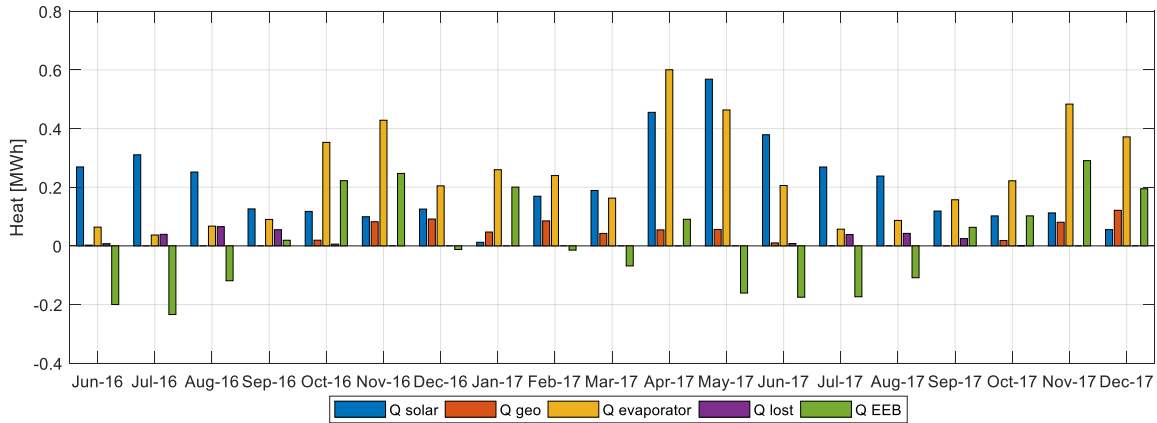


Figure 3. Total monthly energy fluxes of the EEB

Regarding the monthly seasonal performance factor (SPF), Figure 4 shows how the heat pump performs in monthly basis; these results were calculated using Equation 4. It can be noticed that even though the shallow system limits the quantity of heat that the heat pump can extract from the EEB, the SPF is high enough to make the system competitive for domestic applications. The fact of injecting heat in the EEB, even in sunny winter days, allows an increase in EEB temperature and consequent increase in the short and long-term efficiency of the heat pump. In winter months, the average SPF is above 2.3 which is even higher than a conventional domestic air source heat pump.

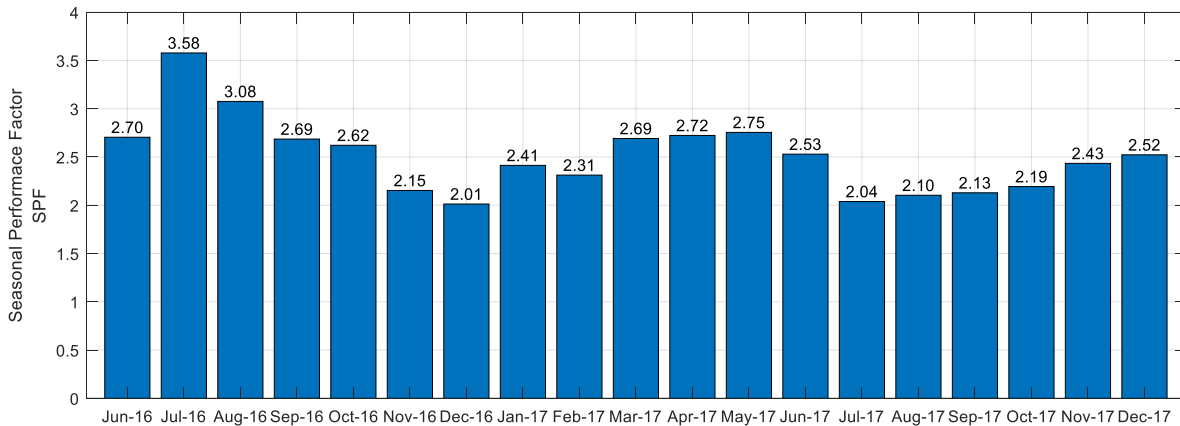


Figure 4. Monthly seasonal performance factor (SPF) of the heat pump

Finally, Figure 5 shows the total energy fluxes integrated for the whole period of analysis. It can be seen that the solar energy is the main energy contributor for covering the evaporator (heating) demands. In fact, 87% of the heat demanded by the heat pump are covered by solar energy while the 13% remaining is covered by geothermal energy (surrounding soil).

An interesting fact that was noticed when analysing the experimental data is that the outlet fluid temperature from the solar collectors is low (25°C in average) as the PVT technology does not allow to have a high outlet temperature. This temperature limits the heat flux to the EEB as the temperature difference with the ground in the EEB would not be very high. If other solar technology that allows having a higher outlet temperature (flat plate collectors or evacuated tube collectors), a higher heat transfer to the EEB would occur and the whole system efficiency might be higher. However, in such system, an intermediate water storage tank or a three-way valve

(between the EEB and the heat pump) would be needed in order to avoid too high a fluid entering temperature at the evaporator.

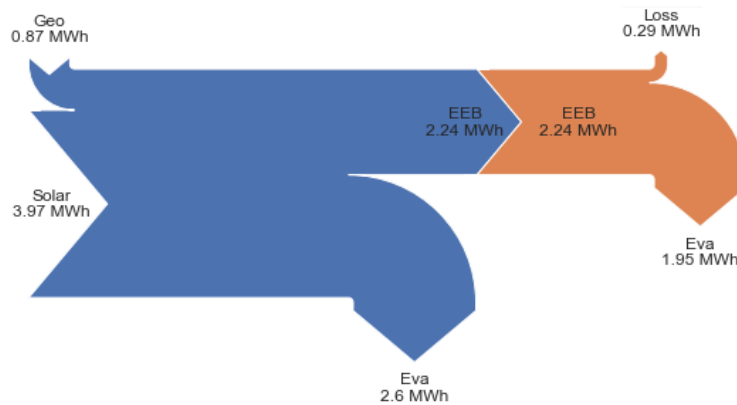


Figure 5. Sankey diagram of the EEB energy fluxes for the whole period of analysis

3.2. Discussion on the potential contribution to the sustainable development goals (SDGs)

From the experimental analysis of this research, it was shown that although more research is needed to improve the system configuration of the shallow GSHP technology, there is a high potential for this technology to be widely used in the domestic heating sector. First, it was shown that the shallow systems are a configuration that indeed can cover the heating demands of a low-energy home (where the peak heating load is typically below 20 W/m^2). Likewise, the cost and speed of installation of shallow geothermal boreholes are very low compared to conventional GSHP systems, as the drilling process would not require the use of robust machinery. Finally, the fact that renewable energy technologies are becoming much more affordable allows shallow SAGSHP technology to be competitive for the domestic sector. Hence, the option of using this technology could be very attractive for the building sector.

On the other hand, considering that this competitive system has an average SPF of 2.5 over the year, this would mean that the required input energy (electricity) would be 40% of the conventional electricity radiators to cover the same demand. However, when compared to gas heating and considering that in the UK the cost per kWh of gas is around 25% of the electricity price, running the shallow SAGSHP would cost 38% more. However, different electricity tariffs could be used, which means that an HP could run overnight and store hot water for space heating and the price could be highly reduced. To do this, a smart control strategy would be required.

Considering that only in England, 160000 new homes are built every year and that a low energy design is being required over time, there is high potential to make a difference in developing the market of clean and affordable energy and make a real contribution to the SDG 7.

4. Conclusions

The objective of this paper is to present the experimental results of a solar assisted ground source heat pump (SAGSHP) that uses a shallow (1.5 m deep) vertical ground heat exchanger and the potential of using this technology to contribute in reaching the sustainable development goal (SDG) 7 which is to reach clean and affordable energy by 2030. It was evidenced that a shallow geothermal heat exchanger could be an affordable option for covering the heating demands of low-energy homes. This technology can be even more effective when used in combination with solar energy for short-term and long-term energy storage. The average monthly seasonal

performance factor of this system was above 2.3, which is competitive compared to conventional air source heat pumps. It was also highlighted that this configuration could be improved in terms of control strategy and the use of intermediate heat storage system to enhance the whole annual system's performance. The potential applicability of this system in England is very high as it is much more effective than conventional electric heating and could compete with gas heating by an appropriate control and storage strategy. If this technology could be applied in a percentage of the new homes' projects, a significant contribution to the SDG7 could be reached.

5. Acknowledgements

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Session 5

Water and health issues in the SDGs

Barriers to Monitoring Water and Sanitation delivery by NGO's: Case Study Ghana

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Abstract

Purpose

In Countries like Ghana, approximately over 50% of WASH activities within the country are carried out by Non-Governmental Organisations (NGOs), of which 25% of water and sanitation facilities become non-operational after five years. The effectiveness of Water Sanitation and Hygiene (WASH) initiatives is crucial to long term sustainable access to improved water, sanitation and hygiene practices. Whether it is lack of continual funding or poor management of WASH activities, there is a clear disparity between the initial focus of improving long-lasting access to water and sanitation and the annual reporting of 30%-50% of initiatives failing after two to three years in urban and rural communities. This paper presents findings from a study of barriers faced by NGOs in the Delivery of WASH projects in urban and Rural Ghana and the impact on achieving SDG six.

Method

The research focused on building a case study of current NGO WASH implementation, monitoring and evaluation in Ghana. This was acquired through the use of semi-structured interviews. Participants included NGOs representatives and beneficiaries of NGO WASH projects in a total of five Districts.

Finding and Recommendation

Sociocultural and economic inequality are prominent in these areas which exacerbates issues of access to adequate solutions. According to data analysed, corruption on all levels of WASH programs is a major set-back in the progression of NGO WASH and as a result creates tension between local leaders and WASH facilitators. Although there is clear indication of progress of WASH activities, closer monitoring of NGO WASH programs especially in Low-Middle Income Economies (LMIEs) like Ghana is crucially required. An implementation of regular monitoring by an independent agent (preferably from outside the country) will help mitigate issues of culture and corruption within WASH operation.

Limitations

Socioeconomic dynamics varies from country to country hence barriers may differ in different LMIEs. However, the case study in Ghana presents current challenges to achieving goal six and what areas may need close monitoring when it comes to future WASH programs. This is essential to achieving Goal six ensuring most vulnerable areas are able to access adequate solutions.

Key Words

NGO, WASH, LONGEVITY, BARRIERS, CORRUPTION, INADEQUATE

Introduction

In 2015, the General Assembly of United Nations Delegates and representatives revised the Sustainable Development Goals with the aim of “leaving no one behind” (United Nations 2015). This included 17 goals intended to contribute to the holistic improvement of international issues, such as health, energy and poverty. Goal six focuses on water and sanitation with emphasis on achieving 100% access to water by the year 2030 and reducing mortality caused by waterborne diseases. International goals have motivated a focus on water and sanitation issues especially in Low-Income Economies (LIEs) and Low-Middle Income Economies (LMIEs) (Drangert and Sharatchandra, 2017). The aim of alleviating water insufficiency and poor sanitation practices is a challenging task for countries with already restricted financial budgets for development, and limited resource capacities, this makes the effort of private and Non-Governmental Organisations essential.

The role of NGOs is key to the delivery of these services, due to their ability to outsource resources and funds in the aid of programs. NGOs are able to focus aid on particular areas of development, such as water and sanitation. These developments may not necessarily be an LMIE government’s priority, however, an essential component of development for the global community recognised by the United Nations Sustainable Development Goal (SDG) Six especially in LIEs and LMIE where WASH is mainly delivered by NGOs (Christensen and Weinstein 2013).

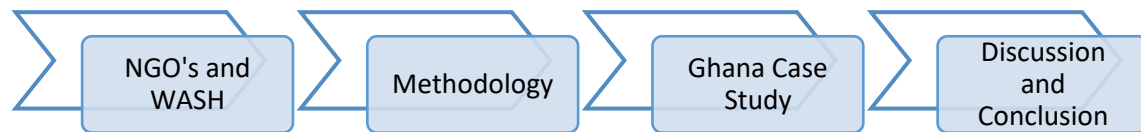
NGOs in Water and Sanitation

There has been an increase in NGO efforts in water and sanitation projects in low-income areas (Kamstra, and Schulpen 2015). The impacts of NGO activities on water and sanitation is significant to sustainable solutions, NGO’s such as WaterAid, Water Mission, UNICEF and Oxfam are major components to the delivery of WASH projects in LMIE’s such as Ghana. The facilities provided by these have improved the standard of living of the urban and rural poor (WHO, 2019). Community-based sanitation system that can operate successfully without being supported by NGO support either pre, during or post-implementation are scarce (Whaley and Cleaver, 2017). As a result, one of the ways of improving the longevity of WASH initiatives is encouraging community participation, NGOs such as WaterAid and Water Mission implement ‘Community-Led Total Sanitation’ (CLTS) as part of their sanitation programs in order to encourage communities to take more responsibility for the progression of WASH activities. This happens when communities assign representatives who are involved in the selection, implementation and monitoring of water and sanitation facilities in their area, these members may include District Assemblies (DAs). In these instances, DAs are encouraged to manage and monitor facilities that have been installed by local or international NGOs. This is noted to increase the longevity of projects and facilities (WSUP, 2017). However, this model of operation is problematic due to the leverage given to DAs and WASH group leaders. In many cases where projects are abandoned, or poorly managed by DAs, NGOs have little power in resolving this due to lack of financial capacity, resources or limited information (Wayland, 2017; Chambers, 2009). Funding on WASH activities are not sustainable long-term due to fluctuating financial aid provision, and therefore scale (implementing several WASH projects) is more important than longevity (maintaining and monitoring existing projects) (WSUP, 2017) in this instance, achieving a long-term sustainable solution could be challenged and potentially compromise the bid to achieve "Water and Sanitation for all".

The question at hand is, what is the long-lasting impact of water and sanitation projects by NGOs in areas targeted and how successful are they in long-term sustainable solution? Fowler, (2007), indicates that although NGOs are important sources of aid, the monitoring framework of projects implemented is usually flawed. When it comes to WASH initiatives it is imperative that there is true accountability of contribution of NGOs effort to inadequate solution alleviation (Joint Monitoring Programme, 2019). This will ensure that there is an accurate representation of aid provision and beneficiaries of aid are accessing adequate solution. Studies by Cumming and Slaymaker, (2018) also highlights the ambiguity with defining WASH “success” especially in regard to NGO contribution. The World Health Organisation (WHO) and UNICEF Joint Monitoring Program (JMP) have unclear definitions of “what is “safe” water; the measurement of appropriateness varies from country to country. This makes it difficult for comparison or uniformed cataloguing of international progress.

This paper aims to identify current barriers to the effective delivery, monitoring and evaluating of WASH initiatives by NGOs in LMIEs drawing on a case study of Ghana. However, before discussing literature on WASH in Ghana, the paper will first introduce the methodological process of the research to give background into the process of data collection before presenting current literature on the state of WASH in Ghana and the need for NGO interventions leading into the primary research conducted in this study. The following figure shows the structure of the following paper.

Figure 1 - Structure of Paper



Methodology

Primary Data on NGO WASH operations was conducted in Ghana with a sample of five districts across; the south, eastern, upper west and two districts in the northern region. The research focused on investigating the barriers and challenges faced by NGO’s and beneficiaries of WASH initiatives in Ghana and the impact of these challenges in meeting SDG goal six. This was done using semi-structured interviews to identify what current operations work well and what does not in the implementing, monitoring and evaluation of projects. NGO Participants were directors and implementers of WASH in the selected locations. Questions focused on identifying how WASH is monitored, who is responsible and how success elements are measured. Furthermore, the scale of NGO operation was examined with questions that focused on the level of operation by the NGO, demand for facilities and longevity of project funding. A total of twenty NGOs participated, of which five were international NGOs, ten national and five local NGOs. Participants in the second phase interviews were beneficiaries chosen from locations in which the participating NGOs operated. Beneficiaries were selected randomly using the data of record of areas that had been supported by participated NGOs. These areas were approached with the permission of the NGOs and the local district leaders. Participants were then selected randomly from the list of houses that had been allocated to avoid biased responses. These participants were asked four questions regarding the aid they receive were asked; who is responsible for facility maintenance, how often are they monitored, what role they play in WASH in

their community and what can be improved with current WASH. A total of forty beneficiaries participated in the research. The results of the interviews were thematically analysed to categorise frequent codes of concerns into themes of barriers. These themes were selected if half or more of the participants regarded it as a major concern or challenge.

Due to the nature of questions and the area of research, ethical code of conduct according to the UK data protection (GOV.UK, 2019) and the De Montfort University ethical guidelines (De Montfort University, 2019) were followed to ensure that, participants remained anonymous and details of location of participating beneficiaries were kept confidential to avoid bridging confidentiality.

WASH in Ghana

The United Nation Millennium Development Goals reflected that Ghana had attained its goal of reducing the number of people without access to safe drinking water by 50% (Luh and Bartram, 2015; WHO, 2018; United Nations 2019). International efforts, especially since the revision of the SDG six, has placed an emphasis on access to improved water and sanitation in urban and rural areas. According to the regulations of the Water Resources Commission (WRC), Act 522 in Ghana, access to water takes priority (WRC, 1996, Mosello, 2017). This has led to an increase of 89% of the Ghanaian population with access to “improved water” (Mosello, 2017) according to the 2015 Joint Monitoring Program, 2015, the definition of “improved water” however is unclear. This improvement also, priorities urban areas, cities and towns while 85% of rural areas still remain with unsafe water (USAID, 2019).

Since the 1990s, Ghana has invested in the building of a structure for the WASH sectors through reforms. Yet, the attention of the government and its development partners focused on the urban water sub-sector, leaving behind much-needed investments in sanitation and rural water. Investments in urban water ‘have been one of the top priorities for the government of Ghana as this process will lead to multiplier effects in improved economic fundamentals and improved development situation of the country (WSP, 2015). The international discourses and strategies for development of the 1990s and 2000s also encouraged investments in urban water. Integrated Water Resources Management (IWRM) principles, and particularly the decentralization of the water sector, have strongly shaped the way in which water supply and service delivery in both urban and rural areas have been treated (WRC, 2014).

This enabling framework had a strong focus on serving the poor and those living in unserved areas, such as urban areas and slums. The pro-poor focus of the government’s strategy for urban water seems to have also been influenced by donors and development partners (Lutalo et al., 2016). For example, the World Bank has provided support for the development of a pro-poor urban water service delivery strategy and a strategy for peri-urban water service delivery with the GWCL and the PURC (GoG, 2014; Lutalo et al., 2016). The focus on urban WASH suggests some level of discrepancy in the selection of the geographic location of WASH development in Ghana. While international efforts for development aims to relieve the “most in need”, the focus of policies within the country targeted improving areas that were more inclined to economic development. Hence, the severity of the health implication of unsafe WASH for rural settlers was not prioritized.

This has been challenged by the civil society and NGOs in the water and sanitation sector who have both noted the inequality in the selection of location when it comes to water development by the Ghana Water Company Limited (GWCL). They argue that the GWCL has not given equal priority to serving the rural areas effectively (Mosello, 2017). As a result, although data shows an increase in access to adequate solutions, this data is a reflection of urban communities, rural areas which have higher cases of waterborne diseases are still not prioritized. This poses a huge barrier to monitoring the progress of

adequate solution in Ghana; data and reality do not match. Hence, there are discrepancies with location selection as well as issues with transparency in the allocation of resources. Furthermore, the progression of WASH activities are scarcely available (Smith-Asante, 2019), this indicates some level of bureaucracy and corruption. This makes the role of NGO WASH crucial to reach areas that are not provided for.

There are other major issues with the current operation of WASH in Ghana, some of which are general to WASH in LMIEs. The challenges identified in the literature (table 1) will be compared to the themes identified from the interviews in Ghana to identify if these themes are still relevant and if there are any new emerging barriers.

Table 1 - Challenges identified in Literature

<i>Challenge</i>	<i>Reference</i>
<i>Limited Human and Technical Capacity-</i> WASH is significantly dependent on human capacity especially when it come to the implementation of sanitation initiatives. However, with decreasing unwillingness to “volunteer” without some form of incentives, projects with limited funds and resources find it difficult to operate effective initiatives.	<i>Jenkins & Sugden, (2014), Evans (2015)</i>
<i>Low Capacity to Absorb Funds-</i> Ghana’s transition to lower middle-income status has had an impact on the level of aid that goes into the country. For example The Official Development Assistance (ODA) reduced aid into the country by 8million (\$). Due to the fact that international aid priorities economic areas that are more impoverished, Ghana moving into a higher economic status shows that they are able to be less dependent on aid. However, the concept of income inequality and unequal economic distribution of wealth is not taken into consideration and further exacerbates poverty gaps within the country.	<i>World Bank (2014, 2015 and 2016)</i> <i>Water Supply and Sanitation (2019)</i>
<i>Complexities of Behaviour Change-</i> although discouraging poor hygiene practices and encouraging good hygiene practices is important within WASH delivery, it will not be enough: just because people know about disease and the cause of disease it does not necessarily mean that they will do something about it. For some locals certain unsafe hygiene practices are deeply integrated with culture.	<i>Jacobs-Mata et al., (2018), Akpabio and Takara, (2014)</i>

Results: Key themes within NGO and Beneficiaries' Responses.

In order to authenticate the progression of NGO WASH activities in meeting the SDG target, Ghana was chosen for further investigation due to their achieving 80% population access to “improved water” (United Nations 2019). Evaluating barriers to further access within the context of Ghana may highlight potential limitations to achieving SDG six for LMIEs.

Following the barriers identified in the literature, similar challenges were anticipated in the primary data in Ghana. Questions were designed to compare claims regarding the challenges faced by NGOs in the delivery of WASH and to establish if the barriers identified in the literature are relevant in WASH delivery to date and detect others that are specific to the country.

A guideline for thematic analysis was followed as a method of analysis of which coding was categorized into two clusters of themes (Guest, MacQueen and Namey, 2012). These were labelled “*barriers according to NGOs*” and “*barriers according to beneficiaries*”. Themes were generated according to the frequencies within which they were mentioned by respondents; those that appeared in ten or more of NGOs’ response and twenty or more out of the forty beneficiaries’ response were considered “major themes”.

Table 2 below presents comprised themes of frequent codes in the response to questions regarding “improving WASH”.

Table 2 - Themes in participants' response

NGO Explanation Summarised	Themes	Beneficiaries' Explanation Summarised
-There were major overlaps in the responses of NGOs and Beneficiaries. Data representing areas of WASH impact are not accurate in some cases, areas within the Northern Region of Ghana has some abandoned NGOs projects. This is not reflected on NGO records hence some data on progress is fabricated.	Corruption	Corruption was noted in 90% of respondents' answers. According to beneficiaries' responses, national political parties play a major role in the allocation of financial aid to NGO projects and some areas are favoured more due to their political affiliation. Hence aid is not allocated due to need but by political biases.

<p>Majority of NGOs interviewed identified that there is a high level of DA bureaucracy when it comes to WASH community teams, DA leaders tend to interfere with information transparency between WASH Community teams and NGOs. Hence efforts to achieve Open Defecation Free (ODF) status is hindered due to an unwillingness to comply.</p>	<p><i>District Assembly (DA) Bureaucracy</i></p>	<p>Beneficiaries identified that some DA set their own rules regarding water point's payments and these can be extortionate prices which some families cannot afford. As a result, some locals tend to avoid using WASH facilities provided and returning to inadequate solutions. This can go on for years before NGOs notice because of the lack of monitoring of WASH facilities by NGOs.</p>
<p>There are major discrepancies when it comes to monitoring. It is unclear who should be in charge of the monitoring of WASH projects in the long term. Responses differed according to the level of operation of the NGO (National, Local or International). Due to the increased pressure of SDG 6, majority of NGO's prioritise "scale" rather than "longevity". Hence investment into WASH Activity is focused on short-term WASH projects (2-3years) rather than long term sustainable solutions.</p>	<p><i>Lack of Monitoring</i></p>	<p>Concerns of beneficiaries are the increased pressure on locals to sustain and maintain Water Facilities. This is sometimes financially constraining and frustration has led to some districts returning back to unsafe water from lakes and Open Defecation. This is highly problematic because although products are in place, monitoring of products are insufficient and solutions are not effective in those areas.</p>
<p>Limited financial support and short-term aid provision mean that NGOs are often left with a tight budget and have to prioritise immediate solution rather than long term ones. This has resulted in an exacerbation of product breakdown due to poor quality product used (rusty water pumps).</p>	<p><i>Lack of Financial Support</i></p>	<p>It is huge enforces on community-led total sanitation which incorporates water points. A huge part of this initiative is encouraging the community to be financially liable for facilities implemented this can come at a financial cost to locals.</p>
<p>Breaking cultural ideas about sanitation and water has been a challenger for NGOs, this has been reflected both in literature and in data gathered in Ghana. There are some superstitious beliefs regarding open defecation which makes it difficult for NGOs to break. According to NGOs the reason for relapse of ODF areas</p>	<p><i>Culture</i></p>	<p>According to of respondents, NGOs often undermine religious and cultural practices, although the majority of beneficiaries understood the health implication of safe sanitation and adequate water, some practice cannot be questioned due to beliefs. e.g. "bathing in dirty water to keep demons away"</p>

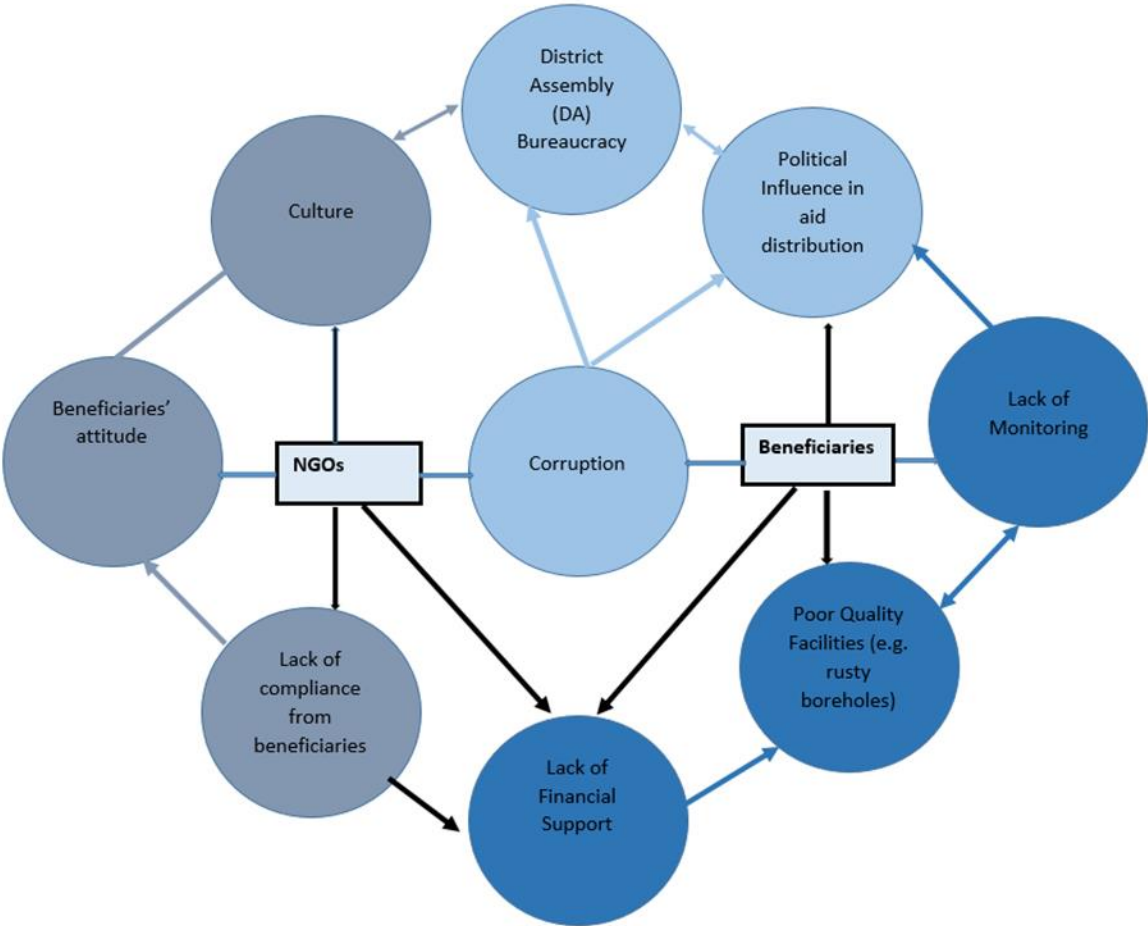
are often linked to cultural resistance		
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Discussion and Conclusion

The themes provided in Table 2 confirms a need for a more structured regulatory system in place for WASH initiatives. Weak governance, culture and limited financial capacity put further constraints on the longevity of projects and as a result, pose major resistance to global efforts of alleviating inadequate solution.

Corruption was a major theme detected in the findings in Ghana, the effects of it had an implication on other themes identified during data analysis which is highlighted in figure two. Phrases such as “we vote to drink water” was a frequent saying of participants from certain locations in the North who felt underserved by their local NGO due to their political affiliation. As a result, locals sometimes are reluctant towards being involved with NGOs, however, in areas where monitoring and supply were more rigorous areas specifically in the south of Ghana, DAs played a major role in the “supervision” of WASH facilities. These were where responses from NGOs suggested DA Bureaucracy.

Figure 2 - Barriers Framework



These results suggested that although there are some similarities with themes in literature, in Ghana's case the interference of politics and corruption are underrated by providing NGOs who sometimes places excessive power in the hands of local governance.

Also, considering the findings in the areas visited in Ghana, some data suggesting "access to improved water in Ghana" may need revisiting. In order to achieve SDG six especially in Ghana's case, closer attention needs to be paid in the implementation, monitoring and evaluation stages of NGO initiative to ensure that these barriers identified are mitigated or closely monitored.

Donaldson (2016) stated that the general consensus is that there is clear evidence of an increase in NGO activities in LIEs and LMIEs; however, the linkage between NGO activities and alleviation of poor water and sanitation solution still needs to be monitored closely (Saleem and Donaldson, 2016). Considering the findings in this research, it is clear evidence of discrepancies in the operation of NGOs in LMIEs and this yields the result of abandoned WASH projects (UNICEF, 2017). Lack of awareness or lack of consideration of barriers such as corruption which has clear implications on beneficiaries 'access to adequate solutions continues to affect the effectiveness of WASH' (Transparency International, 2017).

Nevertheless, the aims of improving the accountability of NGOs' contribution to improving access to safe Water and sanitation can be monitored through the developments of adequate monitoring systems which are universal. Increasing access it is important however without rigours monitoring of barriers, the effectiveness of WASH which is majorly carried out by NGOs lacks validity. There is a current gap between attaining adequate water and sanitation for all and the WASH program.

Limitations

This research is not suggesting that barriers are unanimous across every LMIEs and data found in these five districts do not reflect the operation of WASH in the whole of Ghana, however, the case study in Ghana presents a crucial outlook on the state of NGO WASH operations and challenges faced.

Harvey, Agol and Keraital (2018) emphasise that data on NGO WASH impact lacks statistical validation and rigours scrutiny of its impact in areas such as health, assessing the impact of NGO WASH initiatives in LMIE is complex for a number of reasons.

- Socio-economic dynamics such as the level of education, culture and the local attitude toward WASH improvement are different in each country and the impact of these factors varies widely, as a result, although data may present similarities in barriers across LMIEs. These have their individual weight in terms of the threat they pose to the longevity of projects.
- Universal definitions of "safe water" are not clear, this leaves room for interpretation of data on "improved access to water and sanitation". Although this has been challenged by international agencies such as USAID (2019), and the World Health Organisation (2018) these ambiguous terms mask rate of progression of SDG six and there is no clear resolution to resolve this. Further research is required to identify how these barriers overlap or differ in different socio-economic areas.

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Sustainable development and water-conservation practices in South Africa

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Abstract

Access to clean water and sanitation services plays a very important role in supporting achievement of not only the Sustainable Development Goal (SDG) 6, but also all the other SDGs. Despite the critical importance of water resource, many cities around the world face serious water scarcity, which negatively affects the entire structure of their economic, social and ecological systems. An increasing solution that is currently used to mitigate water scarcity, mainly in cities that experience a growing population, is adoption of water-saving equipment by urban households. This paper seeks to determine the factors that drive adoption of water-conservation technologies that collect, store and eventually treat wastewater within urban households in South Africa. We provide a theoretical framework that uses choice modelling to account for the influence of information sharing and households' risk attitudes on adoption of water-saving technologies. The theoretical model is then tested on data collected from 465 households in the City of Cape Town Municipality. Our results show that both socio-economic and policy variables affect the choice of grey water and other water-saving strategies. The additional advantage of this paper is it allows us to find out whether information provided by policy-makers, about the likelihood for the city to run out of water, i.e Day Zero – i.e., the day when Cape Town totally depletes its fresh water reserves, has induced widespread adoption of water-saving technologies.

Key words: Grey water technologies, technology adoption, water saving behaviour, risk aversion, Cape Town, Day Zero, South Africa

1. Introduction

Achievement of sustainable development goals (SDGs) requires access to basic water services. Many arid and semi-arid regions in the world currently face severe water scarcity. This situation of scarcity hampers economic progress and social development. One approach that has been widely advocated to mitigate water scarcity is adoption greywater treatment technologies that help households reduce the volume of water consumption and hence improve water resources management. Indeed, the use of grey water to mitigate water scarcity is increasingly becoming

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an important research area in cities facing water stress (Katukiza et al, 2014; Achak et al, 2009; Turner et al, 2016). Grey water usually refers to wastewater coming from the bath, showers, kitchen and washing machines that has lower concentration in microbial contents and chemical characteristics than sewage water (Roesner et al, 2006; Eriksson et al, 2002). Grey water is used in most urban areas, for non-potable consumption, to supplement fresh water supplies for household activities such as irrigating lawns and outdoor gardens, cleaning floors, washing cars and flushing toilets. From the demand side, we can think of the use of grey water as a household strategy to economize on fresh water demand and reduce water bills.

This paper investigates the factors that drive adoption of grey water conservation technology in an urban setting such as Cape Town. The underlying argument of our analysis is achievement of SDGs 6 and other SDGs requires not only a universal access to water services, but also a better management of water resources to guaranteed sustainability, cost-recovery and affordability, particularly in the developing countries. Therefore, grey water conservation and treatment technologies are compared with other water-saving equipment (rainwater tank, pond, borehole and rainwater buckets) to investigate the factors that drive adoption of particular water saving technologies in a given water stressed country: South Africa. We build a microeconomic framework that is combined with an empirical strategy to analyse the extent to which socio-economic and policy factors may drive adoption of water conservation measures. Additionally, we investigate whether publicity about the water crisis and, in particular, Day Zero, i.e., the day when Cape Town totally depletes its fresh water reserves, has influenced the behaviour of some of the city's residents to adopt water saving technologies. The proposed model allows addressing questions such as: i) Can information about a water crisis influence household use and adoption of grey water and alternative water saving technologies? ii) What types of households are more affected by such information?

This study contributes to the scanty literature on water saving behaviour in South African large cities by linking the risk profile of households to adoption and use of water saving technologies. Additionally, this study is the first of its kind to investigate the determinants of water saving behaviour in the urban areas in the region. Many previous studies have focused on understanding the factors that drive water saving behaviour in the agriculture. This is because agricultural water use consumes 70 % of the total water in South Africa (StatSA, 2011). The major objective of this work is to provide guidance on solutions that may be undertaken to address water scarcity in the context of developing and emerging economies in order to support sustainable development initiatives. The City of Cape Town in South Africa has recently experienced critical water shortages as a result of incessant droughts and low rainfall spanning a period of almost five consecutive years coupled with lack of investment in appropriate water infrastructure. Media reports indicate that the city almost depleted its fresh water reserves, which could have resulted in a disaster. Hence, understanding the factors that induce water saving behaviour to mitigate water scarcity is central from a policy and academic perspective. Although the current study uses data collected from Cape Town, its focus could be equally relevant for any given country that experiences water scarcity.

Section 2 presents the model that is used to study the behaviour of grey water technology adoption. Section 3 reports the data and sampling strategies that have been used. Results are presented in Section 4, while Section 5 concludes the paper.

2. Theoretical model of grey water technology adoption

The model includes households who are deciding on whether or not to adopt grey water technology among other water-conservation technologies in an urban context. The model₁₉₉

draws from the microeconomic framework proposed in [Jaffe and Stavín \(2002\)](#), [Sunding and Zilberman \(2001\)](#) and [Deaton and Muellbauer \(2009\)](#), but departs from these by focusing on urban households. Most of the water-saving technology adoption literature has been undertaken in the agricultural sector. This is mainly because agriculture captures the bulk of the water demand, both worldwide and within nations. This paper is among the first to study factors that drive adoption of water conservation technology in an urban context in the country. We assume that households pay a price P_w to purchase a quantity of freshwater (Q_w) from the municipality, but could also invest in grey water technology. This additional investment in grey water technology will self-sustain the household since water treated from grey technology could be re-used for non-potable indoor and outdoor consumption purposes. To keep the analysis as simple as possible, we assume that technology adoption will generate (S) volume of grey water at a shadow price (v). Investing in grey water technology allows households to reduce the volume of water purchased from the municipality⁷. Therefore any given single-period budget constraint, conditional on total expenditure, can be represented as in Equation (1).

$$P_w Q_w + v^* S = x \quad (1)$$

where P_w and Q_w represent the price and volume of clean (potable) water consumed within household, respectively, and $S = 1$ if household invests in grey water technology and $S = 0$, if not. The household total budget in a given year is assumed to be x . Let the single-period utility function be represented by Equation (2) below.

$$U = U(Q_w, S, e) \quad (2)$$

where e is a vector of parameters that differ across households and are not reflected in the budget constraint e.g. attitude towards risk, family composition and education level. This paper makes particular emphasis on the risk attitude of households towards Day Zero. Households who do not believe in the occurrence of Day Zero are mapped as risk-neutral, whereas those who believe that Day Zero will happen are categorized as risk-averse households. We start by illustrating the choices made by two hypothetical households A and B using two different indifference curves I_A and I_B , respectively. The curves are presented in Figure 1 below. For instance, if households choose not to adopt grey water technology, the volume of water consumed from the municipality remains at $\frac{x}{P_w}$. Clearly any increase in water price leads to a

fall in potable water consumption. A simple optimisation constraint with law of demand would allow determining the associated elasticity of a change in price as: $\frac{DQ_w}{Q_w} * \frac{P_w}{DP_w}$. Alternatively a

decision to purchase grey water technology would reduce the

volume of potable water consumed to $\frac{(x - v^*)}{P_w}$. The distance between x and v^* captures the influence of grey water technology adoption: $\frac{v^*}{P_w}$.

⁷ Separability is assumed following [Strotz \(1959\)](#).

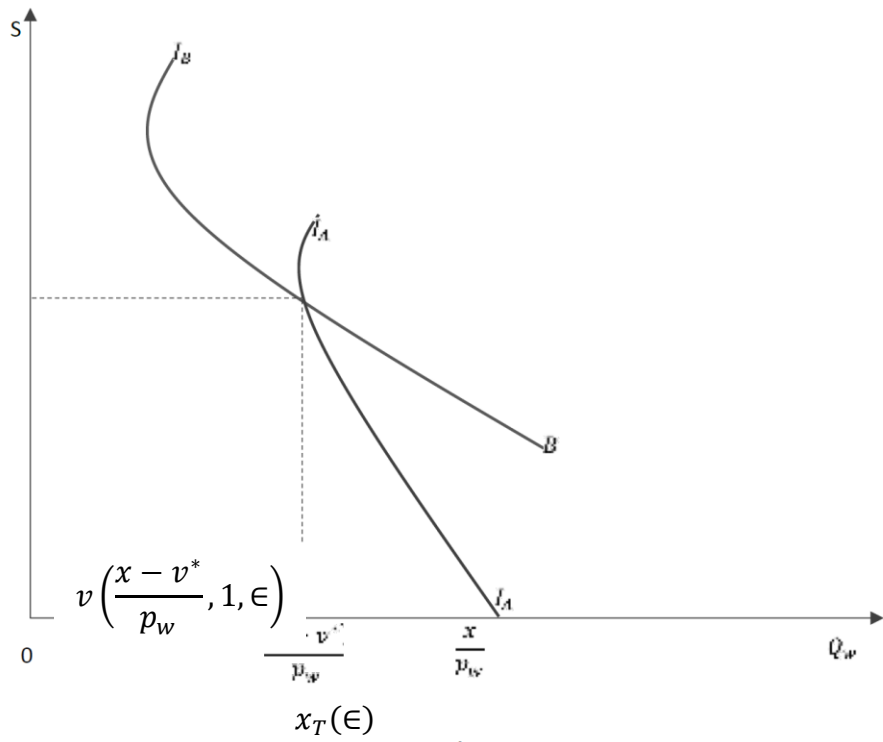


Figure 1

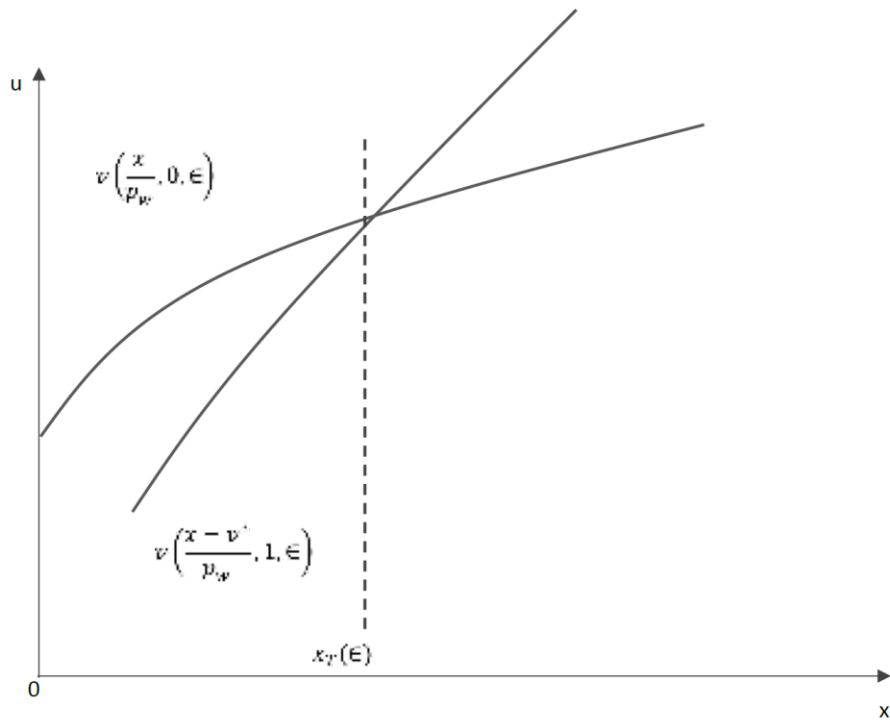


Figure 2

Let's assume that utilities of adoption and non-adoption are represented in the following equations (3) and (4), respectively.

$$u_0 = v \frac{x}{p_w}, S = 0, e \quad (3)$$

$$u_1 = v \frac{x - v^*}{p_w}, S = 1, e \quad (4)$$

Therefore household will adopt grey water technology as long as the utility derived from adoption outweighs its reservation option: status quo; $u_1 \geq u_0$. Which households fall into which category is determined by the values of x and e . If we assume that households have the same level of sensitivity towards risk (risk-averse), but differ in total expenditure x , then it is clear that for poor households u_0 is likely to be higher than u_1 . For households that consume very little amount of water, the marginal disutility associated with non-adoption is large compared to the benefits of adoption. However, as x increases, so will Q_w , until the disutility of a decrease in v/p_w is outweighed by the benefits associated with adoption. This relationship is shown in Figure 2 below, where the point $x_T(e)$ is the threshold point or threshold expenditure. When households reach $x_T(e)$, they would prefer to purchase grey water technology.

Therefore if we represent by $f(x, e)$ the joint density function of x and e , the proportion of households with expenditure x who would adopt grey water technology, $g(x)$, is given in equation (5) below.

$$g(x) = \frac{\int_{-\infty}^{F(x/v^*)} f(x, e) de}{\int_{-\infty}^{\infty} f(x, e) de} \quad (5)$$

where $F(x/v^*)$ is an increasing function of x/v^* . Equation (5) gives a straightforward basis in utility theory for Engel curves that links adoption in any income interval to the income level. Finally, if we assume that e is distributed independently of x and that it has the lognormal distribution with parameters m and S^2 , then Equation (5) could be written as Equation (6) with the proportion of adopters given by Equation (7)

$$g(x) = \text{prob}(S = 1; x) = \int_{-\infty}^x f(e, m, S^2) de \quad (6)$$

$$\text{proportion of adopters} = \int_0^\infty \int_{-\infty}^x f(x, e) d e dx \quad (7)$$

We use a multinomial logit (MNL) and conditional logit (CL) model to demonstrate that risk is an important factor influencing people's decisions. Both models are constrained by the Independence of Irrelevant Alternatives (IIA) assumption, which states that the ratio of the

probabilities of choosing any two alternatives is independent of the attributes of any other alternative in the choice set (Hausman and McFadden, 1984; Tse, 1987). The MNL is used as the baseline model since it is simple and is widely used in the literature to model people's decisions to adopt technology (Hausman and Wise 1978; Wu and Babcock 1998). In contrast, the CL allows us to capture heterogeneity or dissimilarities among different technology-nonconventional water choices. As opposed to the MNL model, the CL model assumes that respondents make decisions about nonconventional water choices conditional on technology.

3. Data collection and sampling

The household survey collected primary data on socio-economic variables, water-saving strategies, rainwater harvesting, and grey water technologies among other policy variables. Ten residential areas were purposefully sampled and, in each suburb, streets and households were randomly selected. The residential areas were carefully chosen so that they represent the different dimensions of the population in Cape Town such as race, income and wealth categories of households. The sampling process was done in two steps. First, we randomly selected the streets in the respective residential areas and the street names were allocated to enumerators. For each selected street, enumerators chose a starting point. The next household was chosen after every n households, where n is the sampling interval calculated as the total number of households in the suburb divided by the required sample size. The selection procedure continued until the required number of households in the sample was achieved. If an enumerator reached the end of the street before the required number of households is achieved, the enumerator moved to another street on the list and the same process starts again by randomly choosing a different starting. The process continued in the same manner until the required sample size in that residential area was achieved.

4. Results and discussion

4.1: Regression analysis

As highlighted earlier, the analysis in this paper uses both the MNL and CL to analyse the drivers of household decisions to use various water-saving strategies or technologies used in Cape Town. We assume the risk that the city might run out of fresh water could be one of the major drivers of technology adoption and utilization, in addition to the other socio-economic variables. Although the results of the two models tell the same story most of the time, both models actually bring in different flavours to the analysis and as a result we will interpret their results jointly as part of the bigger picture. Finally, we use the logit model to understand the individual characteristics that drive the risk profile of respondents⁸.

Tables 1-3 present the estimated coefficients of the MNL, CL and logit model respectively, while the marginal effects are presented in Table A1, A2 and A3 in the appendix. The results show that

⁸ We used a model building technique where the explanatory variables are added or subtracted one at time based on the goodness of fit measures until a plausible model with the best fit is achieved

most of the explanatory variables in the three models are statistically significant at 5% or lower and the signs on most variables are as expected, except for a few variables which are discussed below. Our analysis of the MNL and CL uses the greywater bucket as the base category for the adoption of water saving strategies and evaluates the other choices as alternatives to this option. We choose the greywater bucket as the baseline category because it is the most common and cheaper method that people use every day. The first column of Table 1, for example, compares the choice of rainwater bucket with greywater bucket, where the coefficients and their signs reflect the probability of preferring to adopt a rainwater bucket compared to a greywater bucket if we change an explanatory variable. The same applies to the remaining choices in the Table 1. Similarly, the coefficients of the CL in Table 2 are also interpreted in the same manner.

The MNL model confirms the result of the CL model and illustrates that women are more likely to use much cheaper technologies such as a grey water bucket or a pond than men. Results in Table 2 indicate that the use of ponds to harvest rainwater and as storage facility for greywater is less common in Cape Town. Discussions with respondents during the survey revealed that some of these facilities were recently built as a mitigation measure against water shortages. However, the use of ponds as storage facilities for both greywater and rainwater is problematic as this can easily become a breeding ground for harmful pathogens that cause water borne diseases and sometimes produce bad smell in the neighbourhood. In particular, greywater is known to cause diseases and to produce bad smell if not treated properly (Friedler et al. 2008; Eriksson 2004; Drechsel et al. 2002). But when properly treated, greywater can represent a tangible alternative that helps households reduce impact of water scarcity, without any negative impacts on health.

The CL model shows that both the age and educational level of the household head positively affects the household choices to invest in certain technologies, while the costs of the technology negatively affects decisions. The MNL shows that high education levels tend to be associated with shifting away from greywater buckets to the other alternatives, especially bigger and more reliable technologies. Educated respondents are 1.1 times more likely to invest in rainwater tanks and approximately 0.7 times more likely to use greywater tanks than uneducated people. Educated respondents might have more information and knowledge about water saving strategies and technologies such as their advantage, limitations, available options and potential threats to health (Bakare et al. 2016). An increase in the age of the household head increases the likelihood of households to use a rainwater bucket, rainwater tank, greywater tank and sink borehole in addition to a simple greywater bucket.

Table 1: MNL model results

Number of obs	4619				
LR chi2(50)	965.1				
Prob>chi2	0.000				
Log likelihood	-3728				
Pseudo R2	0.115				
Variables	Rainwater bucket	Rainwater tank	Greywater tank	Pond	Borehole
Age	0.0247***	0.0218***	0.0148**	-0.140***	0.0164***
	0.00713	0.00408	0.00700	0.0259	0.00486

Gender	0.454*** 0.190	0.389*** 0.104	0.615*** 0.178	-2.556*** 0.693	1.193 0.145
Education	0.259*** 0.0590	0.0828** 0.0331	0.221*** 0.0579	0.290* 0.163	0.0819** 0.0413
Income	-0.325** 0.1104	0.0227*** 0.0374	-0.308*** 0.0817	-0.0057*** 0.000104	0.00182*** 0.00456
Household size	0.0896** 0.0433	0.0643*** 0.0238	0.137*** 0.0348	0.484*** 0.109	-0.128*** 0.0346
Day zero	-0.0570 0.189	0.0802 0.103	-1.514*** 0.198	-1.084** 0.512	-0.00926 0.122
Water shortages	-0.254** 0.387	-1.531** 0.5073	-0.0476* 0.6245	0.18127 0.0494	-0.4761** 0.2476
Reduce water bill	-0.277 0.266	0.0783 0.191	19.28*** 0.677	0.619 0.676	-0.267 0.238
Greywater supporters	-0.0197*** 0.00334	0.0101 0.00290	0.00926*** 0.00400	-0.0534*** 0.0111	0.00766 0.00337
Conservationist	-0.00457 0.00297	0.00370** 0.00163	0.0105*** 0.00275	0.0713*** 0.0143	0.0200*** 0.00221
Const	-3.3901*** 0.6425	-4.2113** 0.40029	-2.90459 0.85238	3.3533** 1.7007	-4.7768** 0.5917

Source: results from survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Table 2: Results of the CL model

Number of obs	2,400	
Number of cases	400	
Wald chi2(31)	342.79	
Prob > chi2	0.0000	
Log likelihood	-446.53271	
Choice	Coef.	Std. Err.
Technology		
Age	2.629421**	5.106931
Education	4.17463	2514.281

Cost	-0.0000318**	0.0000135
<i>Rainwater bucket</i>		
Gender	0.4844831	0.355511
Employment	-1.190763***	0.2793135
Dayzero	-0.7555423**	0.338576
Reduce water bill	-0.9154173**	0.3864154
Experienced water shortages	-0.0476121*	0.4082003
<i>Greywater bucket</i> (base alternative)		
<i>Rainwater tank</i>		
Gender	0.4326651	0.3984521
Employment	1.252431***	0.3048312
Dayzero	-0.5984326	0.3783853
Reduce water bill	-1.763806***	0.4344086
Experienced water shortages	-0.1812719*	0.466294
<i>Greywater tank</i>		
Gender	0.0838153	0.5703756
Employment	1.517567***	0.4067391
Dayzero	2.228968***	0.6902548
Reduce water bill	1.729398***	0.6256347
Experienced water shortages	-1.63092*	0.079878
<i>Pond</i>		
Gender	-0.9584884	1.26997
Employment	-2.014701***	0.7335333
Dayzero	-1.522897	1.156426
Reduce water bill	-2.998145***	1.15409
Experienced water shortages	1.37833	1.0834
<i>Borehole</i>		
Gender	1.476081**	0.6325251
Employment	1.349407***	0.456971
Dayzero	-0.0117438	0.5234026
Reduce water bill	-1.248402	0.8598482
Experienced water shortages	-0.1643154*	0.605834

Source: survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Table 3 presents the results of the logit model where we try to link the characteristics of respondents to their risk profile. We can think of the respondents who indicated that they believe in Day Zero as risk averse and those who do not believe in Day Zero as either neutral or risk loving. Our results show that the belief that Day Zero exists and most likely the risk behaviour²⁰⁶

of individuals is explained by socio-economic factors of the respondent such as age, gender, education, location and inclination towards nature. No evidence was found of the role of income in explaining or influencing people's belief about whether Day Zero exists or not.

The logit model results illustrate that older respondents are 0.2 times less likely to believe in Day Zero. This result contradicts expectations, since evidence from empirical and theory studies suggest that young people are generally more risk taking than older people (Bonem et al. 2015; Rolison 2013; Albert and Duffy 2012; Jackson 2012). We believe that the results depend on context, i.e., the type of risk we are considering, beliefs and trust that the city authorities are saying the truth. Discussions with respondents revealed that older people generally think that the City of Cape Town is not telling the truth and the crisis is a result of mismanagement of resources.

Table 3: Results of the logit model

Number of obs	5135	
LR chi2(6)	148.5	
Prob>chi2	0.000	
Log likelihood	-3471	
Pseudo R2	0.0209	
Dayzero	Coef.	Std.Err.
Age	-0.00565**	0.00223
Gender	-0.259***	0.0001
Edu	0.0597***	0.0193
Locations		
Matland	0.6198***	.204537
Plumstead	0.54543***	.1942358
Southfield	0.3094	.2005307
Wynburg	1.54	0.123
Goodwood	0.1937	.2016502
Oakdale	-0.7549***	.2000495
North Pine	-1.084***	.3832611
Brackenfell	0.05279	.2057589
Kensington	0.6060**	.2600351
Income	0.05467	0.023906

Conservationist	0.00181*	0.000925
Cons	0.834	0.174

Source: results from survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Men were 0.1 times less likely to believe in Day Zero than females. This is consistent with theory and empirical evidence since males usually portray risk behaviour than females (Harris and Jenkins 2006; Nelson 2012). Well educated respondents are 0.8 times more likely to believe in Day Zero and thus more risk averse than their less educated counterparts. This could be a result of information asymmetry between the two groups as educated people are usually well informed. Bernardi (2002) demonstrated that the risk behaviour also depends on information or knowledge posed by an individual. This analysis supports the result of the MNL model that educated people are more likely to invest in reliable technology maybe because of risk aversion.

5. Conclusion and policy recommendations

Adoption and use of grey water technologies is increasingly becoming important for cities experiencing water scarcity such as Cape Town. This adoption is expected to spur achievement of SDGs that target an improvement in human conditions, especially in poor countries that experience severe water shortage.

Our results demonstrate that both socio-economic and policy variables affect choice of water saving strategies used at household level in Cape Town. As age, education and household size increases, households are more likely to use a rainwater bucket, invest in either a rainwater tank, greywater tank, construct a pond or sink a borehole in addition to a simple greywater bucket. Males are more likely to choose a rainwater bucket, rainwater tank, greywater tank and to sink a borehole than to use a greywater bucket, while females are more likely to choose cheaper grey water pond.

Respondents who believed in Day Zero or risk averse are likely to use a simple greywater buckets than to choose other strategies, and are more likely to invest in greywater tank than a greywater bucket. Greywater technologies are very reliable since they yield more water for other household non-potable consumptive activities on a daily basis and throughout the year compared to rainwater technologies and boreholes. Inclination towards conservation increases the probability of investing in technologies that yield more rainwater and greywater than a simple greywater bucket. The results of the logit model show that older people and men respondents are less likely to believe in Day Zero, while educated respondents are more likely to be risk averse. There is no evidence of the role of income in explaining the risk profile of the respondents.

From a policy perspective, the use of information about potential disasters is likely to change the behaviour of respondents with risk aversion only to adopt greywater technologies. This study calls for the use of training and awareness campaigns to inform people in urban areas about greywater technologies, i.e., available options, their advantages and health implications. There is need for other methods to incentivise risk neutral and risk loving individuals to adopt technologies because information alone might not change their behaviour. For example, appropriate incentives can be provided to households that adopt greywater technologies and vice versa. These incentives can come in the form of a reduced water bill or subsidies on greywater technologies so that many households are able to purchase them.

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ANNEXES

Table A1: MNL model results

Variables	Marginal Effects (dy/dx)				
	Rainwater bucket	Rainwater tank	Greywater tank	Pond	Borehole
Age	0.0042* 0.0031	0.0188* 0.0138	0.0006** 0.0048	-0.0013* 0.0048	0.006 *** 0.0062
Gender	0.0672* 0.082	0.2816** 0.3636	0.892** 0.2158	-0.0006*** 0.0735	0.0584 0.0382
Education	0.0478** 0.0404	1.0657* 0.1247	0.718*** 0.0875	0.0260* 0.1052	0.0339** 0.0665
Income	-0.734** 0.2015	0.967*** 0.0004	-1.957*** 0.0001	-0.0019*** 0.0015	0.8251*** 0.0396
Household size	0.0174** 0.0213	0.0643* 0.0923	0.0079*** 0.0583	0.0376*** 0.218	-0.0708*** 0.0174
Day zero	-0.0867 0.0750	0.0802 0.103	-1.028 *** 0.5783	-0.0080** 0.0413	-0.0003 0.0424
Water shortages	-0.0470* 0.029	-0.0958* 0.0808	-0.0476* 0.245	0.0027 0.0375	-0.3672** 0.2585
Reduce water bill	-0.0645 0.0357	0.0634 0.1657	2.0284*** 0.0306	0.0524 0.263	-0.0027 0.0009
Greywater supporters	-0.0419 *** 0.00334	0.0093 0.0042	0.735*** 0.0418	-0.0627*** 0.0026	0.0035 0.0002
Conservationist	-0.0125* 0.00386	0.0023** 0.0054	0.0005*** 0.0394	0.0073** 0.0003	0.0010*** 0.0062

Source: results from survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Table A2: Results of the CL model

Choice	Marginal Effects (dy/dx)	
	Coef.	Std. Err.
Technology		
Age	0.5814*	1.2812
Education	0.4335	5.0457
Cost	-0.0867**	0.0966
<i>Rainwater bucket</i>		
Gender	0.0452	0.1003
Employment	-0.0542***	0.1128
Dayzero	-0.0206**	0.0475
Reduce water bill	-0.0834*	0.2010
Experienced water shortages	-0.0142*	0.0872
<i>Greywater bucket</i> (base alternative)		
<i>Rainwater tank</i>		
Gender	0.0721	0.2153
Employment	0.7186*	0.2129
Dayzero	-0.0725	0.0623
Reduce water bill	-0.2911***	0.3674
Experienced water shortages	-0.0630*	0.3423
<i>Greywater tank</i>		
Gender	0.0032	0.0642
Employment	-0.0217**	0.0802
Dayzero	1.6275***	0.0342
Reduce water bill	0.9810*	0.2042
Experienced water shortages	-1.5377*	0.0827
<i>Pond</i>		
Gender	-0.0181	1.3106
Employment	-2.0794**	0.5617
Dayzero	-1.258	0.5132
Reduce water bill	-2.1213***	1.0267
Experienced water shortages	1.0785	1.5240
<i>Borehole</i>		
Gender	2.0337**	0.3553
Employment	1.0390***	0.4100
Dayzero	-0.0089	0.0965
Reduce water bill	-1.0758	0.7959
Experienced water shortages	-0.0149*	0.1627

Source: survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Table A3: Results of the logit model

Dayzero	Marginal Effects (dy/dx)	
	Coef.	Std.Err.
Age	-0.192**	0.00055
Gender	-0.068***	0.01449
Edu	0.791***	0.00479
Location	0.02875***	0.00297
Income	0.0767	0.0528
Conservationist	0.00045*	0.00023
Cons	0.834	0.174

Source: results from survey data 2018

* significant at 10% ** significant at 5% *** significant at 1%

Achieving sustainable development goals with an R&D prize platform for neglected diseases

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Abstract

Eradication and control of neglected diseases, which are often called diseases of poverty, are crucial to achieve such sustainable development goals as good health and well-being, economic growth, and reduced inequality. Neglected diseases cannot be eradicated or even properly controlled without development of new medicine, but they do not attract commercial pharmaceutical R&D due to insufficient markets, despite that over 150 countries and over two billion people are at risk, and a few million die every year from these diseases. Market failures essentially block commercial development of new drugs for neglected diseases, while alternative publicly supported innovation models have limited success and considerable deficiencies in targeting product quality, resource mobilization, and knowledge sharing. This article develops a new incentive model for drug R&D that combines the desirable features of the main public innovation models for neglected diseases into an open innovation platform (ecosystem) with subsidised clinical trials, knowledge sharing, and a prize payment in proportion to marginal product quality improvement. The organization and management issues of the platform are elaborated to address the needs of small pharmaceutical companies and academic groups targeting better quality drugs with fully subsidized clinical trials for selected product candidates. The platform openly calls for product candidates evaluated with the wisdom of mostly volunteering crowd of experts, and winners are awarded with two payments: the first payment provides financial liquidity to winning innovators, while independent clinical trials reduce costs and risks of R&D for innovators and allow estimation of product quality for the second prize, which is paid in proportion to the marginal product quality. Calibration of the model for the case of tuberculosis indicates potential for significant benefits and cost-effectiveness improvement.

Keywords: neglected diseases, innovation ecosystem, open innovation, linear contract, incentives, pharmaceutical R&D, tuberculosis.

JEL: O31, H87, L17, I15, L32, L65

Introduction

Achievement of number three sustainable development goal (SDG3) “good health and well-being” requires eradication and control of about fifty neglected diseases (NDs), that kill few million people annually. Success against NDs also helps to reduce poverty (SDG1), hunger (SDG2), and to improve work and economic growth (SDG8) as healthy workers can produce more and families would spend less due to illness, which could reduce inequality between healthy and unhealthy family members (SDG10), enhance justice to patients in terms of access to proper medicine and to reduce disabilities (SDG16), enable more sustainable cities and communities (SDG11) as well as increasing resilience to climate change (SDG13) by preventing epidemics, while higher longevity could encourage education (SDG4) (Bangert et al., 2017). The proposed platform is also in line with formation of sustainable global partnerships (SDG17).

While over three billion people in more than a hundred countries are at risk from neglected diseases (NDs) (Kar, 2010), many NDs have no effective cure due to little R&D effort. Only 4 per cent of new therapeutic products and 1 per cent of new chemical entities registered from 2000 to 2011 were indicated for 49 NDs, which have 11 per cent share in the global burden of diseases (Pedrique et al., 2013). The main reason for this is that limited market size combined with patients’ constrained and unstable purchasing power make investment in R&D for NDs commercially unattractive for the pharmaceutical sector (Berdud et al., 2017). NDs are one of the leading causes of the poverty trap for the “bottom billion” people, and both control and elimination of most of these diseases is impossible without development of new drugs, vaccines, diagnostics, technologies, and strategies (Hotez et al., 2016). Moreover, the health convergence of developing countries to the level of best performing middle-income countries by 2035 is not possible without new improved health tools (Jamison et al., 2016).

We propose an open platform – an ecosystem targeting small liquidity-constrained firms and academic groups whose potential has been underutilized. Our model combines the desirable features of the existing innovation schemes for NDs into an open innovation (OI) platform incentivised by a linear contract for economic incentives to provide a robust solution with good potential for efficacy gains. In linear contracts the reward to agent is a proportion to benefits (output) for the principal, and this contract with proper settings guarantees a positive optimal surplus for principal even with some renegotiation possibilities (Chassang, 2013). We calibrate our model to the case of tuberculosis: the WHO (Zumla et al., 2015) calculated 9 million cases with almost a half million of very costly and more dangerous multidrug resistant new cases with fifty thousand of extensively resistant cases with no available treatment, and 1.5 million people died of tuberculosis in 2013. For fifty years hardly any new drugs for tuberculosis (TB) have been developed (Dheda et al., 2016).

The proposed two-stage open innovation public-private partnership platform (2SOP)

In practice, the global character of NDs and knowledge spillovers from R&D suggest that an open innovation (OI) strategy in combination with the desirable features of the existing innovation schemes for NDs may offer a better solution. OI has four dimensions: networks, organisational structures, evaluation processes and knowledge management systems (Chiaroni et al., 2011). The OI strategy, however, still faces serious challenges of integrating the diverse crowds with large knowledge gaps and risks of contentious conflicts and self-promotion as documented in the management literature (Malhotra et al., 2017).

The platform in the context of the current R&D incentive schemes for NDs

By way of a starting point for determining the optimal features of a new OI platform, Table 1 summarizes the advantages and disadvantages of the proposed and main existing schemes, which rely on either ‘push’ or ‘pull’ incentives (Towse et al., 2012). The right-hand column notes various ways in which our proposed platform incorporates the strengths of these schemes while also addressing the challenges which they reveal.

TABLE I. THE MAIN ADVANTAGES AND DISADVANTAGES OF ND-RELATED R&D INCENTIVE SCHEMES: WHAT THE PLATFORM ADOPTS AND ADDS

Scheme /operating or theoretically proposed /	Advantages	Disadvantages	Features adopted and added in the proposed Platform
Advanced Market (Purchase) Commitments (AMC), an active model (Berndt et al., 2007), which is based on a forecast contract paying out on attainment of predefined drug characteristics. The model has been piloted with \$1.5 billion AMC for pneumococcal vaccines in LDCs.	The rule of payments for pre-specified quantity and quality of drugs are set in advance, guaranteeing a sufficient market for one-time drug improvement. The prize is paid on delivery of the product, which reduces the moral hazard of innovator (Kremer and Williams, 2010).	Monopsony power of one buyer; difficult advanced specification of the complex product (Hecht et al., 2009). Possible overpayments by donors for overstated (by producers) drug benefits; difficult to set a fair market commitment; advance sponsors are needed (Maurer 2005). Open drug licenses are not targeted. This may favour late-stage lower risk drug candidates (Berdud et al., 2016). The model favours large companies as it is riskier for smaller liquidity-constrained innovators (Grace 2006). Sporadic AMCs may lead to incremental innovations and lack of knowledge generation and sharing as some large firms tend to focus on commercialization (Arora et al., 2018). The scheme can be manipulated by inflated sales (Chari et al., 2012).	As in the AMC, the prize rules are pre-set, with a major payment on successful product registration. But the pay-out is proportional to the drug quality advancement; early-stage R&D by liquidity-constrained innovators is encouraged with a small first prize. The costs and risks of R&D are shared by subsidized clinical trials for selected product candidates. The drug is not delivered to the consumer, but open public licenses are secured to allow immediate generic production.
Priority review vouchers (PRV), an active model (Ridley et al., 2006) under a 2007 US law, which grants a saleable priority review voucher in exchange for a new drug for NDs.	Stable source of funding, no sponsors are needed, minimal claims on drug regulators.	Unconvincing track record, suggesting that the core incentive may be inadequate (Berdud et al., 2016). No consumer access at generic prices or knowledge sharing. Rewards are not calibrated to quality of innovation (Kesselheim, 2008).	The PRV could provide a significant supplement funding for the platform by selling vouchers for developed drugs and sharing such proceeds with innovators.
Non-profit public-private partnerships (PPPs), product development partnerships (PDPs). Publicly-funded non-profits typically target a single disease such as malaria, AIDS, and tuberculosis.	Flexibility and collaboration with various partners, which could be private. PDPs account for 40% of drug R&D pipeline for NDs (Ponder and Moree, 2012).	Obstacles to cooperation (Moran, 2016) as learning from one project may not be re-used in another due to unique combinations of product partners. Problems of post-contract opportunism of research partners. A need for committed donors and volunteer contributors. Some partnerships suffer from lack of efficient governance/transparency (Mrazek and Mossialos, 2003). <i>Ad hoc</i> negotiations with partners preclude more universal efficient management routines and do not guarantee steady incentives for all partners, lack of coordination across partnerships may reduce R&D productivity (Hollis, 2006).	Platform (ecosystem) partnership with innovators, flexibility in partnership choice with standardized coordination across partners; improved scope for risk diversification and resource sharing across projects; transparency and accountability as requirements.
Orphan Drug Incentives under a 1983 US law, later also adopted in Japan in 1993 and in the EU in 2000 targeting some domestic NDs.	Combines push (tax credit, lower drug registration fee) incentives with pull incentives such as several years of market exclusivity after patent expiry.	Requires high and extended period of market exclusivity - monopoly pricing, which conditions R&D on continuous charging of high drug prices; difficulties with price differentiation between rich and poor patients (Trouiller et al., 2002). No specific knowledge sharing provisions.	Orphan Drug Incentives provide additional incentives for innovators in rich countries with ND patients. However, in developing countries these incentives are unlikely to work: NDs are often called “diseases of poverty”, and high drug prices driven by market exclusivity are incompatible with aims to eradicate NDs.

Call options on future approved drugs with discounted price with feasibility estimates for antibiotics (a theoretical proposal) (Brogan and Mossialos, 2016).	A systematic proposal with flexible financing with a right of advance purchase.	Unclear market valuation of options for drug quality owing to the uncertainties of early-stages R&D. Viability requirement of sufficiently deep and liquid trading of such options (Roth, 2008) may be unattainable. The option pricing requires a mechanism for early screening of drug candidates, which may not provide sufficient information for an investor.	The right to buy new drugs at lower prices due to an advance contribution is useful. Upper-middle- and high-income countries can subscribe, for a periodic fee, to the right of obtaining new products developed by the platform as generics.
Government-backed bond financing of R&D (a theoretical proposal) (Hecht et al, 2009).	Potentially, this is a more stable source of funding than in-kind donations and allow to commit R&D expenditures in advance.	Could be more expensive than direct public funding (Hecht et al, 2009). Weak delinking between R&D costs and drug prices as bond holders require a low risk stream of profits coming from higher drug prices. Unclear how ensure low default risk, reasonable return and volatility of bond prices to make them attractive for investors.	Fostering governments' commitments to long-term R&D expenditures.
The Health Impact Fund proposed in (Banerjee et al., 2010), which stipulates a binding global agreement on public reimbursement of drug developers based on their global contribution to health improvements. The WHO's Consultative Expert Working Group (CEWG) on R&D also calls for such binding agreement with governments' contribution 0.01% of GDP for infectious and neglected diseases (Balasegaram et al., 2015).	The information on health impacts of drugs can be revealed to enable well informed prescription; the compensation could be based on estimations of actual improvements in global health; delinking rewards from prices, but some market signals in form of drug sales/usage are used for estimations. Global coordination and priority setting for R&D.	Difficulty of estimating global health impacts, especially in incremental QALYs across many developing countries (Sussex et al., 2013). Even with implausible binding global health R&D agreement, the Fund sharing across different drugs might be complicated. The scheme can be manipulated by inflated sales (Chari et al., 2012). Specific management and structural solutions of the Fund are not clear.	Evaluation based on marginal health impacts, not sales, but evaluated by means of fully disclosed clinical trials. No price regulation, but open license for the contracted products for a specified list of countries, which limits rent seeking by allowing immediate generic production and distribution in those countries. Formation of better global R&D portfolio. The idea of CEWG about contributions of 0.01% GDP: the platform could work with at least one contribution in five years from all governments of the upper- and high-income countries, whose total annual GDP exceeds \$50 trillion.

As the market failure for NDs is based on very small market size, and the elasticity of new chemical entities by market size is about 0.23 even for large lucrative pharmaceutical markets, it requires around \$2.5 billion in sales to make R&D of a new drug commercially viable (Dubois et al., 2015). Our model for the tuberculosis case shows that this hurdle could be about 3-6 times lower.

The platform structure, management, and event sequence

The platform respects the prerequisites of best management practice, as identified by (Bloom and van Reenen, 2010) as having clear operational processes, transparent monitoring, benchmarks for drug targets, performance measures and prize incentives for innovators, while disincentivizing inferior projects. The main difference between our proposal and the previous push and pull incentives is that the platform is intended to develop a scalable R&D modular ecosystem with uniform contractual agreements and standardised relationships, which combines efforts of a large number of autonomous innovators, donors, experts, clinical research organizations, pharmaceutical companies, and customers in developing countries. Each member of the ecosystem benefits from the network and has compatible incentives with shared visions, high interdependency, competition among innovators, a clear structure of complementary roles, it welcomes new members and satisfies needs of all ecosystem's parts in targeting high quality drugs. The platform comprises three main participants: the principal, innovators and experts (Table 2).

TABLE 2. THE PLATFORM ORGANIZATIONAL STRUCTURE.

Members	Tasks	Finance
Principal - the Board of directors		
Representatives of key donors (World Bank, WHO, Development agencies such as DFID, USAID) Health ministries and NGOs of key disease endemic countries, for example 'doctors without borders'	Set disease priorities and monitoring of operations; Ensuring transparency and publications of key results; Setting the reward coefficient k for the second prize Collecting user feedbacks and improving governance of the platform.	Loans from the World Bank, crowd funding through the platform's website Donations from the governments, organizations and individuals. Selling priority review vouchers for approved drugs and sharing the proceeds, say, at 50:50 deal with the innovators. Positive listing of upper- and high-income countries that contribute subscription fees in amount of 0.002% of GDP annually or 0.01% of GDP once in 5 years.
Management company		
With professional knowledge of clinical trials and the pharmaceutical industry.	Public relations, raising media attention to NDs; Design and management of crowd funding and crowdsourcing; Developing standardised applications for innovators and clinical research organisations (CROs); Open calls for newly patented drug/treatment candidates; Developing standardised protocols, including guidelines for outsourcing of clinical trials. Finding and contracting experts and evaluation of their ranking of drug/treatment candidates. Tender (contracting out) with CROs with experience in developing countries. Management of funds and human resources. Social media communication and publication of clinical results. Ethical soliciting of donations. Banishing unethical users. Accumulation and systematization of donated or open access materials, compounds, patents, models, libraries, datasets for NDs to enable their user-friendly search. Transparent and explained decisions. Facilitation of exchange between innovators, donors, and suppliers. Organization of web forums, seminars and conferences. Communication with stakeholders Distribution of financial prizes based on tests' results. Registration of new drugs and sale of priority review vouchers for them. Annual reports on facilitation of platform interactions.	Management remuneration with up to 20% of raised funds
Innovators - agents:		
Small pharmaceutical firms and academia-based groups.	Filling applications and supply of drug candidates, monitoring of the clinical trials. Signing public licenses for their drug/product candidates in the countries listed by the Board.	Rewarded with two prizes: a fixed first prize (\$5 million), and the second prize based on drug quality. Also receive a share in the selling priority review vouchers. Innovators enjoy full patent rights in countries not listed by the Board.
<i>Experts:</i> Invited volunteers: professionals in health care, pharmaceutical industry and academia	Evaluate drug candidates based on forms/protocols of the management company. Advising on clinical trials and disease priority	Mostly volunteers, but key experts can be compensated.

The reward system

Innovators would be rewarded with 'prize' payments in two stages. Staged financing has become a standard means for venture investors to withdraw from non-performing projects and to reduce agency costs that arise from asymmetric information and moral hazard problems (Witt and Brachtendorf, 2006). In the first stage, fast liquidity incentives are offered to innovators in the form of a small first fixed prize awarded upon acceptance of a drug candidate onto the

platform. In return, the innovators sign a contract with the platform (the Board) and allow open public licensing for production and distribution of their product in countries specified by the Board. The second major follow-up prize is proportional to the new drug's incremental efficacy as evaluated in phase III fully subsidized and independent clinical trials. This second prize automatically adjusts the reward based on the marginal drug quality, which is estimated in independent clinical trials.

We propose to focus only on one key criterion for setting the second prize – the gain in QALYs (DALYs) per cost of treatment (diagnostics) in comparison to a set benchmark treatment (drug). This is needed to avoid the known multitasking problem in contract design when an additional task reallocates agent's attention and effort away from another with more focus on easy achievable task (Holmstrom and Milgrom, 1991). A simple linear contract can deliver close to optimal incentives: under broad conditions of moral hazard (post contract opportunism) and risk averse agent with limited wealth, the principal can always obtain at least 95% of the benefits available under an optimal non-linear unrestricted contract (Bose et al., 2011). The drug evaluation estimates the ratio of quality-adjusted life-years (QALYs) or disability-adjusted life-years (DALYs) saved by a new drug to its estimated treatment price p in independent clinical trials. This ratio is referred to as the *drug quality* (θ). For each disease, a typical *benchmark* drug or treatment and its quality θ_0 are estimated and announced before drug candidates are selected to prevent wasting scarce resources on inferior R&D projects.

The risk-neutral Principal maximizes the expected QALYs saved given the budget constraint by setting three major controls: the amount of the first prize F and the second prize $S(\theta, \theta_0)$ as a function of own θ and the benchmark drug quality – the threshold θ_0 . The Principal sets these two prizes (F) and (S) to deter low quality drugs by fixing incentive compatibility constraints for innovators, while encouraging the submission of the most promising drug candidates to reduce the costs of clinical trials. To save space, in brief, we find the following solution for the prize model. The principal should pay the first prize $F=R(\theta_0)$ in amount equivalent to the expected research costs of pre-clinical trials leading to the benchmark drug quality θ_0 , and the second prize payment

$S=k(\theta-\theta_0)=k\Delta\theta$ in proportion to the marginal new drug quality. The higher the payment rate k , the more pre-clinical research time (effort) is invested by the innovator to develop a better-quality drug. The second prize payment is zero, if clinical trials show that new drug quality is equal or less than the benchmark drug, hence, the principle does not pay the second prize for an inferior new drug, and this disincentivize innovators with low drug candidates entering into the platform. The innovator finds it unprofitable to enter into the platform, if (s)he knows in advance before committing research that new drug quality will be lower than the benchmark.

Estimates for the case of tuberculosis

The estimations presented here are closer to the maximum budget assuming that all drug candidates will come from pre-clinical stage. The coefficient k might be calibrated based on the expected or needed change in drug quality $\Delta\theta$. A good outside option for a small pharmaceutical firm is about \$100-200 million for vaccines and antibiotics, which implies the first prize $F=\$5$ million, and the second prize $S = V-F \sim \$195$ million (Sharma and Towse, 2017). The out-of-pocket costs of all clinical trials for a new anti-TB agent in developing countries such as India and South Africa would be about \$9.9 million and would last 7-10 years (Villa et al., 2009).

If the Principal wishes to reduce its overall failure rate to less than $\alpha=5\%$, the probability of failure q for all n independent trials would be $(1 - q)^n \leq 0.05$, hence, the minimum number

of drug candidates $n \geq \frac{\log(\alpha)}{\log(1-q)}$. Estimations of the likelihood of approval of over seven thousand drug candidates registered in the US from 2003 to 2011 ranged from 10.4 per cent for all to 15.3 per cent for lead indications, and 16.7 per cent for infectious diseases (Hay et al., 2014). A 20 per cent overhead cost is assumed for the platform’s small administration and body of expert volunteers – similar to the 20-30 per cent overhead estimated for traditional commercial R&D.

Table 3 shows the expected and 95 per cent confidence level of the platform assuming a Bernoulli distribution, the first payment $F = \$5$ million, and the maximum second payment of $\$195$ million, the costs of clinical trials $C = \$10$ million, and with 20 per cent overhead costs.

TABLE 3. EXPECTED COSTS OF THE PLATFORM FOR TUBERCULOSIS, US\$ MILLION.
This version is based on (Sharma and Towse, 2017) estimations of expected NPV benchmark for commercial R&D at \$200m

Probability of individual drug candidate success, q	Minimum number of drug candidates to reduce the platform failure to less than 5%, $n \geq \frac{\log(\alpha)}{\log(1-q)}$	Expected number of successful drugs, nq	The expected maximum costs of the platform, $[n(F+C)+S*3]*(1+20/100)$ with 3 approved drugs	Expected costs per successful drug, expected costs of the platform divided by 3 approved drugs
0.1	29	2.9	1224	408
0.15	19	2.85	1044	348
0.2	14	2.8	954	318
0.25	11	2.75	900	300
0.3	9	2.7	864	288
0.35	7	2.45	828	276
0.4	6	2.4	810	270

Note: assuming Bernoulli distribution for project success, the maximum second payment $S=\$195$ m, the first payment is $F= \$5$ m, costs of clinical trials is $C = \$10$ m, and 20% overhead costs; rounding up to the nearest digit. The estimations reflect a conservative approach in budget costs as the costs could be lower with better candidate portfolio management.

As the budget constrain is likely to be the primarily limiting factor, the parameter k for the second prize can be practically set by the budget constraint for the maximum second payment. The rate of payment k should be determined in wider consultations between sponsors and innovators, and benchmark products and the first prize should be updated every, say, ten years to provide a certainty horizon for innovators.

Conclusion

The proposed platform combines the desirable features of the existing proposals such as delinking drug R&D and price, payment for a marginal drug quality, providing liquidity for small innovators with the first prize, open innovation approach by sourcing major components of pharmaceutical R&D, full information disclosure, some budget sustainability with priority review vouchers, benefits of the platform in terms of standardized coordination, and economies of scope and scale. The linear prize contract is robust to shocks or unknown actions of the agent and facilitates near optimal innovation effort (Bose et al., 2011, Carroll, 2015) leading to better drug quality. The main difference of this platform proposal from other innovation models for NDs is that it aims at creation of self-sustainable innovation ecosystem with better opportunities for donors, innovators, and disease endemic countries to attract variety of liquidity-constrained innovators with diverse products and ideas.

This platform forms a sustainable global innovation ecosystem (SDG17) and can solve the problem of supplies of quality drugs at generic prices for all NDs, which could enormously contribute to solution of the SDG3 in low income countries, which, in turn, reduce disastrous spending of poor families on expensive and ineffective drugs. Hence, this platform also contributes to poverty (SDG1) and hunger (SDG2) reduction as healthy workers can earn

more and enhance economic growth (SDG8), and also meet rights of patients to access to medicine (SDG16).

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Session 6

Presentations from a distance

Energy Access through Cross Border Electricity Trade: Pathway to Achieve SDGs in South Asia

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Abstract

Regional Energy Co-operation in South-Asia could ensure electricity access and development outcomes. Bangladesh is one of the least electrified countries in South Asia, with lowest per capita electricity consumption in the region. It imports 660 megawatts (MW) electricity from India through Cross Border Electricity Trade (CBET) which will soon be 1300 MW. We studied the socio-economic impacts on the lives of the people residing in Bhangapara and Dhakipara villages in Bangladesh which got electrified after the import of electricity from India to Bangladesh began in 2013. The study shows that the access to electricity has direct and indirect impacts in improving income, communication, transport facilities, health, education, and employment generation in a short span of time in the village. It also shed light on the key impacts CBET can have on a micro scale, on the lives of the poor and helps the country in achieving the Sustainable Development Goals (SDGs). Regional energy cooperation in South Asia can help to achieve sustainable energy access. It has the potential to achieve other SDGs linked with access to electricity vz. quality education, gender empowerment, improved livelihoods and good health.

Keywords: Regional Energy Cooperation, Sustainable Development Goals, Cross Border Electricity Trade, South-Asia, Bangladesh

1. Introduction

Energy is a major determinant for accessing vital necessities such as food, water, health care and education (Department for International Development, DFID, 2002). Research has proven that access to modern energy is a key factor contributing to rural development (Chaurey et al., 2004), which is why the livelihood struggles of poorer communities is often instigated by their inability to access modern energy services. Despite the need for energy access for all, it is estimated that approximately 1.3 billion people still do not have access to electricity (International Energy Agency, IEA, 2014), making energy poverty a major factor affecting development.

Around 24.3 percent of the population in Bangladesh live in poverty and 12.9 percent of the population live in extreme poverty (The World Bank, 2016). Nearly 26 per cent of the population and nearly 13 million rural households do not have access to electricity. Furthermore, those with access to electricity in the rural areas have poor electricity supply and routinely experience supply disruptions.

Bangladesh is majorly dependent on natural gas for meeting its energy needs and the supply of natural gas under its current usage rate is expected to run out by 2030 (Hossain, 2018). Bangladesh will have to brace for a shift in its energy mix. During this transition period, there is a need for exploring viable energy sources to meet the demands of a growing population. At present, coal plants and other forms of primary energy are being contemplated, but the issue of planning and constructing large infrastructure is a time consuming process. Not to mention the debates that follow the plan processing stages.

Bangladesh, has also made investments to expand its Renewable Energy sector which will not be enough to meet the country's existing energy needs. So, it is important to acknowledge the potential of exploring Cross Border Electricity Transfer (CBET) opportunities with neighboring countries. Bangladesh shares its borders with India and Myanmar, and is currently engaged in bilateral electricity trade with India.

At present, Bangladesh imports 660 MW electricity from India through CBET using two different transmission lines and portals located in two different parts of the country. This new addition to Bangladesh's electricity supply allows the country to provide electricity to the corners that were previously left in darkness. Rapid increase in electricity supply without engaging in the lengthy process of electricity production means immediate attention can be given to villages that were previously not prioritized for electrification.

This study has tried to better understand the benefits of CBET between Bangladesh and India. The objectives of the study are to assess the socio-economic impacts of electricity in selected bordering villages of Bangladesh that got electrified after the import of electricity from India began. This will help shed light on some of key impacts CBET can have on a micro scale, on the lives of the previously deprived population and how it helps the country in achieving the Sustainable Development Goals (SDGs).

2. Literature Review

2.1 Current Status of Energy and Power Sector in Bangladesh

The Power Sector Master Plan- PSMP (2016) of Bangladesh estimates that the maximum power demand for 2020 and 2030 in the country will be 12,949 MW and 27,434 MW respectively. In the business-as-usual scenario, the energy production at its current pace will be unable to meet the country's growing energy needs unless expansion of the energy sector is prioritized.

At present the country relies mainly on domestic natural gas: approximately 53.74 per cent of the energy mix is dominated by natural gas. According to the Seventh Five Year Plan (FYP) Bangladesh already used up 13.032 Trillion Cubic Feet (TCF) of natural gas from its recoverable reserve of 27.12 TCF (as of 2015). Despite the increase in demand for gas according to the PSMP domestic gas production was 2500 Million Cubic Feet Per Day (mmcf) in 2015 and is predicted to reach approximately 2700 mmcf in 2017, after which it will start declining. In order to meet the increasing gas demand the country has already started taking steps for importing Liquefied Natural Gas – LNG (GED, 2015). Although LNG is considered a cleaner source of energy in comparison to coal, Bangladesh's dependency on imported LNG will expose it to international gas trading prices.

The Seventh FYP forecasts that by 2030, the share of coal will rise up to almost 50 per cent of the energy mix in the country. While coal seems to be an economically favorable option at present, there are two things that should be considered. First with increase in the coal-fired power stations in South Asia the supply of coal will be strained leading to unsustainability in the quality and price of the coal. Secondly, with the threat of climate change the need to divest from fossil fuel will increase resulting in more investments in technologies surrounding the alternative sources of energy. Currently, there is a high potential for solar energy to become cheaper and more accessible in the near future (Coren, 2016) which means that the future prices of coal-based power plants might not be the best solution from a global perspective.

The capacity of Renewable Energy in Bangladesh (as of October, 2017), is 2.82% of the total energy mix; the majority of the renewable energy mix is covered by Hydropower (50.9 percent) followed by solar energy percentages (48.2 per cent). Given the geography and topography of the country the winds are of low speeds, limiting the generation of sufficient electricity from wind energy. In terms of hydropower—since most areas are lower than 9 m above sea level—the potential for energy through hydropower is also limited. Bangladesh has, however, made remarkable progress in terms of solar energy. The country has installed more than four million solar home systems (SHS) and is one of the leaders in Solar PV systems worldwide (Molla, 2017). According to the Renewable Energy Policy (REP, 2008).

Bangladesh has set a target of obtaining 10 per cent of its total energy through renewable sources by 2020. But, the major barrier that prevents expansion of the RE sector in Bangladesh is scarcity of land. As per the policy in Bangladesh large infrastructure for generating renewable energy cannot be developed in arable agriculture land. Since, the country is already densely populated and, with limitations of land availability, the scope of developing RE plants to generate a large quantity of electricity is extremely difficult.

The PSMP (2016) predicts that if the maximum potential of power generation through RE sources is 3700 MW, and if the technologies in practice are pushed to its maximum potential and connected to the grid, Bangladesh can generate approximately 4200 GWh per year. But this is still quite a small percentage when compared to the projected total grid energy generation of 82,000 GWh in 2020 and 307000 GWh in 2040 (Power Division, 2015).

Given the above scenario, Bangladesh has a significant power demand to meet in the coming years and considering the costs and limitations of the primary energy sources currently in use, the country needs to explore options beyond primary energy production.

2.2. Energy Access through CBET in Bangladesh

Currently Bangladesh imports 660 MW electricity from India through CBET using two different transmission lines and portals located in two different parts of the country. The cross-boundary electricity imports between Bangladesh and India began in 2013 through Baharampur (India) and Bheramara (Bangladesh): a 400 Kilovolt (KV) double circuit line passes through the two substations in the two countries and allows Bangladesh to import 500 MW through this connection. However, this substation has the capacity to export another 500 MW and is open for upgrading in the near future. The second initiative is through the 47-km double circuit transmission line linking the power grid at Suryamaninagar in Tripura to the Comilla power grid in eastern Bangladesh. Initially, 100 MW electricity was imported by Bangladesh, but in March 2016, the country started importing a further 60 MW through this line. There is potential to enhance the electricity import through this portal as well.

An analysis on the economic benefits of Bangladesh-India electricity trade conducted by Integrated Research and Action for Development (IRADe) under South Asia Regional Initiative for Energy Integration shared some of the major benefits of CBET as experienced by Bangladesh. Some of the key points include the enhancement of the power sector, the reduced cost of electricity supply and the many socio-economic improvements that resulted from this trade. For Bangladesh, one of the key benefit is that power import through CBET will reduce the country's dependency on imported gas, which has a volatile market and would eventually lead to an increase in the local price of gas. The study revealed that importing electricity from India is one of the most economical choices for Bangladesh and since this prevents the country from having to exploit its natural resources and developing fossil fuel-based power plants, it reduces the country's carbon dioxide emissions and has notable environmental benefits. The funds saved from not having to invest in new infrastructure for the power sector can now be invested in other sectors and help boost the country's economic growth. Importing electricity instead of producing electricity through primary energy sources will also expedite the process of providing electricity to the target population: remote villages that were previously un-electrified can be given electricity without having to go through a long waiting period.

3. Methodology

For the current study a primary field survey based study approach was adopted in order to understand some of the impacts of grid electrification in rural Bangladesh. The prime focus was to capture the experiences and impacts from the beneficiary's point of view.

The study was conducted in two villages Pakuriya Bhangapara and Dhakipara in Ramkrishnapur union of Kushtia district in Bangladesh. In each of the sites, socio-economic surveys were conducted wherein perception of the people was captured through household surveys and focused group discussions. In total Fifty household surveys and twenty Focused group discussion (FGD) were conducted in both the villages which involved people from different households.

The selection process was random as long as respondents represented different households. Special attention was given to ensure that the sample size had a good mix of male and female respondents. The study methodology is shown in figure 1 below.

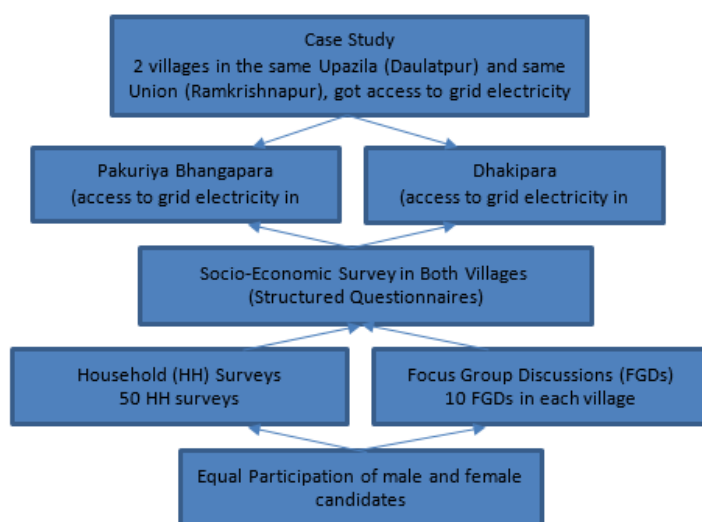


Figure 1 Study Methodology

The questionnaires for both household and focused group discussions were structured to tap information regarding socio-economic conditions of the respondents' household as well as the role played by electricity in their lives. The aim of the FGDs was to facilitate open discussions beyond the scope of the household survey. Further a pilot testing of the questionnaires was conducted prior to the field visit to help reduce any errors and ensure that the questions can easily be understood.

The questions aimed to discover the opinion and experience of the beneficiaries regarding key issues that will provide a better understanding of the usefulness of grid electricity and identify any existing gaps and barriers in the system. This methodology was used to extract qualitative data in the form of personal experiences and opinions to better understand the overall experience of the community as a whole. Information extracted from the surveys was then compiled and analyzed to know the impact of electricity on the lives of the people in the selected sites.

4. Analysis and Discussions

4.1. Study Site

In 2013 Bangladesh for the first time imported 500 MW of electricity was from the Baharampur substation to its own substation in Bheramara in Daulatpur, Kushtia. The Beharampur-Bheramara transmission line enters Bangladesh from Pakuriya Bhangapara, a border village located in the same upazila (sub-district) of Daulatpur in Kushtia district. Bangladesh's 64 districts are divided into Upazilas, which are further divided into Unions (rural area), cities (urban area) and municipalities (suburban area). Pakuriya Bhangapara and Dhakipara are two villages in the Ramkrishopur Union that were electrified in 2014 and 2015, respectively. Of the 19 villages in this Union, 5 have been electrified so far. The following case study is based on these two villages: Pakuria Bhangapara and Dhakipara. The main criteria taken into account when selecting the sites for this study include:

1. Location of the village to be studied
2. The sites to be close to the point of entry/substation through which electricity is being imported
3. Ensuring that the majority of the case study village population got electricity connection after the import of electricity from India began

4.2. Study Findings and Discussion

Electrification in Ramkrishnapur occurred in parts; the whole village was not electrified at the same time. While the government started taking measures for electrifying the village in 2010-2012, only a small fragment of the population got access to electricity. After which, electrification of the rest of the village was somewhat forgotten. From the study sample, only 28 per cent of the respondents shared that they got access to electricity in 2010-2012. The majority of the population in the villages got electricity after the trade began through CBET in 2013. It was seen from the study that around 68 per cent got electricity from the grid line from 2015. The small fraction of 4 per cent without electricity still rely on kerosene, which was the source of electricity for most of the village before it had grid connection.

The change post electrification has touched every resident in Bhangapara and Dhakipara, bringing economic prosperity to the 300 plus households in each village. The immediate impact of electrification in Dhakipara was that land price shot up by 25 – 40 percent. Small businesses grew in both villages because shops now stayed open even in the afternoons in the comfort of electric fans. Earlier the sweltering heat drove owners to down the shutters. Several young men acquired new skills in computer-printing, mobile repairing and operating battery charged rickshaws, particularly in Pakuriya Bhangapara, and started new businesses in the village. Electrification of the villages also affects other activities; for example, 26 per cent of the village people can now use electric motors for pumping ground water. Collected groundwater is used for cooking, bathing, washing and drinking purposes.

Access to electricity also changed life in so many ways by just extending the day. Shops stayed open after dusk; children studied late into the evening, the girl child's school attendance improved because she did not have to gather firewood any more, and women spent far less time on cooking. The following subsections and table-1 give brief of livelihood changes and highlight some of the socio-economic impacts derived from accessing electricity.

- a) **Education:** Majority of the respondents said that their overall education capacity has increased in recent years. Some of the respondents also shared that since getting access to electricity, they have developed new skill sets. They have better technical skills and can engage in new business

opportunities. Most of the people said that they have household members who can now study at night and the main source of energy for this is electricity. Around 58 per cent shared that their family members can now study at night for an additional one to two hours, while 42 per cent of the household members can continue studying for an additional three to four hours. After electrification, the community schools now have light and fan facilities, which encourage students to attend school. Having access to light and fan (during the summer) allows children to perform better in school, as their understanding of school curriculum increases and their interest in higher education is also likely to increase, allowing them to have better career opportunities in the future.

- b) **Work Opportunities and Income:** Around 36 percent of the surveyed population were engaged in farming; 34 percent had other jobs in the service sector including working in NGOs, government offices or shops; around 8 percent were day laborers and 16 percent receive income from businesses. Access to electricity in Ramkrishnapur helped improve their overall agriculture productivity. For example, electric motor pumps are now used for irrigating land and having light at night lets farmers work for longer hours. The storage stations for agriculture products also have lighting facilities, which allows them to keep the stored products in a more hygienic environment. Having access to electricity in a community broadens the scope for work opportunities beyond the primary sector. At least half of the population shared that their average income rose since electrification. The rise in income is mainly through a wider range of livelihood options, scope for introducing new businesses, increasing the amount of working hours and having women contribute toward income generating activities.
- c) **Impact on Gender:** From the surveyed population set, almost half of the women have gone to school. As part of the norm, most women have traditionally been helping their families within the household. However, 14 per cent of the women have now started income generating activities. A number of participants said that participation of women in economic activities has increased since the villages had electricity access.

As discussed through FGDs, working hours within the households have also increased after having light beyond daylight hours. Around 16 per cent of the female respondents have savings and 8 are land owners. Having light at night lets women engage in activities such as tailoring, sewing and making handicrafts, thus making their life better. Having light also gives girls more time to finish their daily duties around the household, which allows them to attend school during the day and still complete their chores during the evening. Some of the women shared that they can even cook at night. This is a significant change because it is customary for females in the village to conduct household chores and previously that is all they would have time to do. The female respondents also indicated that they spend less time collecting alternative fuel (firewood) after getting electricity access. With more light at night, the local area is not as dark as it used to be and women now feel safer to travel after evening hours.

- d) **Connectivity and Accessibility:** In both the villages there has been noticeable improvement in terms of mobile phone connectivity in recent years since electrification. Having access to mobile phones allows people stay socially active and connected with networks within and out of the village vicinity. The participants shared that they also have access to computer facilities in the community. Having access to electricity has enabled people to avail opportunities beyond the scope of their village.

The villages in Ramkrishnapur have better links and improved road facilities since they got electricity access as the connecting electric line passed directly through the village and its setting up and maintenance required engineers and government officials to make frequent visits to the area. Since they have better transport links and improved connectivity, they can now go to

the nearby Upazila and, in some cases, Kushtia district to avail better hospital services when needed.

Table 1 Benefits from electricity access in the selected villages and how it paves the way for achieving the sustainable development goals

Services generated after CBET Trade in Bhangapara and Dhakipara	Effects	Positive Impacts	Linkage with Sustainable Development Goals
Electrification	Increased land prices Improved infrastructure Investments Connectivity	<ul style="list-style-type: none"> • Wealth generation • Transport • Health • Education • Income 	<p><u>SDG 7: Affordable and Clean Energy</u></p> <p>↓</p> <ul style="list-style-type: none"> • SDG 1: No poverty • SDG 2: Zero Hunger) • SDG 3: Good Health and Well Being • SDG 4: Quality Education • SDG 5: Gender Equality • SDG 8: Decent work and Economic Growth • SDG 9: Industry, Innovation and Infrastructure • SDG 13: Climate Action
Lighting	Hours of Study Change in time use	<ul style="list-style-type: none"> • Education • Health 	
Mobile Phones	Communication	<ul style="list-style-type: none"> • Savings • Employment • Income • Education 	
Cooking	Reduce air pollution Utilize time for productive activities	<ul style="list-style-type: none"> • Time saving • Health • Education 	
Computers, TV	Information Knowledge Skill Development	<ul style="list-style-type: none"> • Jobs • Income • Health and Well Being 	
Transport	Increased Mobility	<ul style="list-style-type: none"> • Time and Cost Savings 	
Fan/Coolers	<ul style="list-style-type: none"> • Increased Working hours • Reduced heat stress 	<ul style="list-style-type: none"> • Income • Health • Education 	
Refrigeration	Storage of vaccines Medicine Storage	<ul style="list-style-type: none"> • Health 	
Water Pumping	Clean and potable water	<ul style="list-style-type: none"> • Time savings • Health 	

4.3 Scope for Improvement

Electrification of Ramkrishnapur has brought numerous advantages for the people residing in the villages in this Union. However, there is scope for improvement, and discussion with the residents of the village revealed that they face problems such as load shedding during peak hours of the day and, during disaster events, the electric line is often damaged, resulting in power cuts. Enhancing the amount of electricity and ensuring proper maintenance of electric lines—especially after disaster events—should be ensured for improving the quality of electricity.

Other recommendations include expanding the use of electricity to increase community activities and providing streetlights throughout the village. The respondents said they would like more knowledge and training facilities for better utilization of electricity so they can maximize the uses of electricity and create bigger impacts.

5. Conclusion

Globally, 1.3 billion people are without access to electricity, of which around 338 million are in South Asia. Energy poverty is one of the key reasons for the lack of economic development and low gross domestic product (GDP) in South Asia. Sustained economic growth in South Asia is highly dependent on enabling sustainable generation, transmission and distribution of electricity within the region. Differing resource endowments, development needs and demand patterns among the countries in South Asia create significant opportunities for cooperation and trade in the energy sector.

Bangladesh is one of the least electrified countries in South Asia. Almost half the people in rural areas are still living in dark with no supply of power. Importing electricity from India is one of the most economical choices for Bangladesh. Since this prevents the country from having to exploit its natural resources and developing fossil fuel-based power plants, it reduces the country's greenhouse gas (GHG) emissions and has notable environmental benefits.

A more equal distribution of energy can contribute to greater equality in gender, health, nutrition education, economic development and growth in the world. While CBET offers huge benefits, there are various related technical, political and regulatory challenges that need to be addressed in a timely and effective manner. But it is well worth the effort as CBET has huge potential to support South Asia's aggressive pursuit of economic growth and help achieve SDGs.

The study clearly highlights the importance of electricity in pushing the socio-economic development and fast tracks the achievement of SDGs in South-Asia. Achieving SDG 7 has a significant impact on the achievement of most other goals including Goal 1 (Poverty), Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 4 (Quality Education), Goal 5 (Gender Equality), Goal 7 (Affordable and Clean Energy), Goal 8 (Decent Work and Economic Growth), Goal 9 (Industry, Innovation and Infrastructure) and, of course, Goal 13 (Climate Action).

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What determines uptake of modern fuel: A case study of India

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Abstract: While access to cleaner fuel is a sustainable development goal, the transition from traditional to clean fuel is yet to be fully achieved in India. This paper estimates fuel-costs associated with this transition and analyses the determinants of access to electricity for lighting and Liquefied Petroleum Gas (LPG) for cooking. State-level regression models based on data from 61st (2004-05), and 68th (2011-12) rounds of National Sample Survey are used. While energy expenditures are found to be comparable for kerosene and electricity for lighting, it increases 3.6-8.8-fold for transition to LPG from traditional fuel. Availability is important for greater uptake of electricity i.e. higher rate of electrification helps, but the same is not true for LPG. While untargeted tariff-subsidy leads to significant budgetary pressure, it doesn't improve the access. States with higher income and literacy rate/women empowerment have greater access to LPG and electricity. This shows while Indian energy policies always focused on removal of supply-side barriers through infrastructure creation, removal of first cost barrier and tariff subsidization, a more meaningful way to ensure universal access is perhaps to integrate energy policies within the broader development policies that deal with improvement in socio-economic indicators and remove demand-side barriers.

Keywords: Energy access; Energy subsidy; Energy availability; Women empowerment; India

1. Introduction

‘Access’ to clean and modern fuel at an affordable price is United Nations Development Program (UNDP)’s seventh Sustainable Development Goal (SDG). The goal not only includes energy access for electricity and clean fuels for cooking but also renewable energy and energy efficiency. This present study looks at the energy access perspective of this goal. At global level, the percentage of population having access to electricity was 87% and 59% for clean fuels for cooking by 2016. It is expected to grow to 92% and 73% given the current trajectory of growth by 2030. The corresponding figure in India, in terms of energy access goals is as follows: ~ 84% of people have access to electricity and ~ 41% of population use clean fuel for cooking by 2016. In terms of energy access goals for electricity about 30 million people in India have achieved electricity access every year between 2010-16. In case of LPG India had been able to expand access faster than population growth between 2014 and 2016 (World Bank, 2018). To ensure household access to electricity and LPG, there has been a surge of policies in India during past decades. Interventions to increase availability are in the forms of creation of infrastructure for electricity and increase in the density of LPG distributors. Affordability is addressed through the removal of first cost barriers and tariff subsidization.

2. Transition from traditional to modern fuel and the cost associated

Among various types of fuels used in India for cooking and lighting, firewood, chips, coke/coal and dung cake are the traditional fuels while LPG and electricity are modern and cleaner fuels. Kerosene stands somewhere in between. Transition from traditional to modern fuel may not be a costless process for households. An analysis carried out in the present paper suggests that for a household with demand for cooking fuel equivalent to 1 cylinder of LPG (i.e.~14 kg of LPG) per month, energy expenditure on cooking fuel will increase 8.8-fold if the household shifts from dung cake to LPG and likewise for other fuels (Table 1a). The implications are somewhat different for lighting service. A comparison of a kerosene lamp with a 100W electric incandescent suggests that the monthly expenditure on energy will remain same whether the household uses the lamp or the incandescent for similar hours a day (Table 1b). The movement of the household from traditional to modern sources of fuel which also implies a transition from low cost to high cost and efficient fuels is what is referred to as the concept of energy ladder. The concept of energy access for electricity and cooking as given by SDG 7 where by it talks about ensuring affordable, reliable, sustainable and modern energy for all seen in the backdrop of this study also moves in tandem with the concept of energy ladder.

Table 1a: Different types of fuels and expenditure incurred to meet the same energy demand for cooking

Fuel	Average Calorific Value considered (KCal/Kg)*	Price/kg in INR**	Fuel expenditure per month for 14 kg LPG equivalent (in INR)
Cow-dung cake	3290	1.20	55.34
Biomass	3850	1.46	57.25
Firewood	3175	2.83	134.99
Kerosene	10300	24.00	352.31
LPG	10800	34.91	488.71

Table 1b: Different sources of household lighting and expenditure incurred

	Energy consumption per hour*	Price per unit (in Rs.)**	Monthly energy expenditure in Rs. (5 hour use/day)
Incandescent (electricity) Luminous Flux- 1200	100 W	3	45
Kerosene Lamp (Wick:2.7 mm thick and 95 mm of inside diameter) Luminous Flux- 50	0.03 lit	10	45

*Source: (energy consumption and lm): (Schwarz et al., 2005)

**Source (Price): (Banerjee et al., 2015) (Saikia, 2016)

***If a family uses 1 LPG (14 kg) for cooking per month, the requirement for Calorific value is 151200 Kcal/month

3. Policies to address household energy access in India⁹

The design of the policies in India shows that efforts are extended primarily to remove supply side constraints through increased availability and affordability.

The policies for electrification in India tried to enhance energy access via infrastructure building seen as increasing availability and free connections to some section of people by enhancing affordability. In National Electricity Policy (NEP) (GOI, 2005), the emphasis was mainly on infrastructure creation by increase in the rate of electrification in India. The scheme *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY), launched

⁹ For the analysis, the states in India have been categorized into five regions based on the regional classification provided by the Central Electricity Authority (2012-13).

in April, 2005 used the term access for the first time whereas the focus was both on availability and affordability. *Deen Dyal Upadhyaya Gram Jyoti Yojana*, (DDUGJY) launched in July 2015, subsumed RGGVY. This policy addressed not only the infrastructural concerns but also talked about quality of power supplied to the rural areas and appropriate targeting thereby putting more focus on energy access. More recently *Pradhan Mantri Sahaj Bijli Har Ghar Yojana* (SAUBHAGYA) has been launched in September, 2017 for ensuring the last mile connectivity by providing electricity connections to all remaining un-electrified households in rural and urban areas of the country (GOI, 2017). There is a shifting emphasis to make sure that households have ‘access’ to electricity along with ensuring its availability (Kemmler, 2007; Reddy, 2015; Alkon et al., 2016).

The schemes for LPG mostly addressed the affordability dimension to enhance access. Under the Public Distribution Scheme (PDS) Kerosene and Domestic LPG Subsidy Scheme 2002, the government provided fiscal subsidy to domestic LPG consumers. In 2004, subsidy on domestic LPG was supplemented by a way of under recovery i.e. the losses suffered by the oil marketing companies (OMCs) on account of sale of petroleum products at subsidized price. There was a steady rise in the under recoveries upto 2013-14 until the Direct Benefit Transfer for LPG (DBTL) was launched in 2013. Under DBTL subsidy on LPG cylinders would be directly credited to the Aadhaar¹⁰ linked bank accounts of the beneficiaries. Along with the price subsidy, benefits were launched in terms of installation cost waiver for LPG under *Pradhan Mantri Ujjwala Yojana* (PMUY), launched in 2016. The LPG connections under the scheme was planned to be provided in the name of female member of the households with a financial support of INR 1600/- for each LPG connection to cover the first cost of the equipment. Also, OMCs would provide installment facilities for meeting the cost of stove and the first refill. In 2009, the central government launched a scheme, *Rajiv Gandhi Gramin LPG Vitaran Yojna* (RGGLVY). The focus was to increase LPG penetration through increased number of LPG distributors. This, along with *Pradhan Mantri Gram Sadak Yojana* (PMGSY), a nationwide plan to provide connectivity and to enhance rural road network was expected to increase the availability of LPG.

4. Analytical framework

The present study aims to analyze the role of policy driven supply side determinants related to availability and affordability along with some important demand side determinants such as income and education/empowerment, etc. A state level analysis has been carried out based on micro-panel data regression models to understand the role of such determinants in twenty-eight Indian states. The period of study includes 2004-05 and 2011-12 as for these years the latest quinquennial survey data of NSSO (61st and 68th rounds) are available on Household Consumer Expenditure (NSSO, 2007) (NSSO, 2015). For LPG, a set of Ordinary Least Square Regressions is additionally run for the year 2014 based on 71st round that was a Health Expenditure round. The main sources of data are different reports from 61st and 68th rounds of NSSO. More specifically, the reports on Household Consumption of Various Goods and Services in India and Energy Sources of Indian Households for Cooking and Lighting from both rounds have been used in this study. Other than NSSO, Annual Report (2013-14) on Working of State Power Utilities and Electricity Departments (Power and Energy Division), Planning Commission, Government of India; Directorate of Economics and Statistics (Central Statistical Organization) and Census of India 2001 and 2011 were used as data sources.

¹⁰ Aadhaar is a 12- digit unique identification number for residents of India based on biometric and demographic data.

Altogether results from six panel regression are reported in order to understand the determinants of households' access to electricity for lighting and LPG for cooking. STATA 14 was used to run the regressions.

The general model can be described in the following manner:

$$Y_{it} = \alpha + X'_{it}\beta + D'_{it}\varphi + u_{it} \quad \dots\dots\dots(1)$$

Where, Y_{it} , the dependent variable is the weighted proportion (or proportion) of households that use electricity for lighting/LPG for cooking as primary fuel in state i (or rural/urban area of state i) at time period t . X'_{it} represents the set of non-binary explanatory variables that captures policy induced supply side interventions related to availability and affordability and other demand simulating factors, and D'_{it} represents a vector of dummy (binary) variables included to capture the time-invariant properties such as location of the states in terms of rural/urban and regional location (= 0 if urban, 1 otherwise). The interaction between the dummy variables and the other variables are also included in some of the models. α is the constant intercept of the model. Based on the specification of the error term, a choice is made between random effect, fixed effect models and pooled regression

5. Results and Discussion

5.1 Determinants of LPG access

The results obtained from the LPG models are as follows:

LPG Model 1

$$\text{LPG_S} = -181.6 (-4.52) - 0.65 \text{LN_LPG_P} (-0.1) + 0.97 \text{LPG_DENSITY} (1.2) + 20.21^{***} \text{LN_PC_NSDP} (4.07) + 0.14 \text{F_LITERACY_T} (0.67) - 0.07 \text{ELEC_RATE} (-1.02) + 0.99 \text{REGION_N} (0.15) - 2.58 \text{REGION_S} (-0.34) - 3.65 \text{REGION_E} (-0.48) + 5.63 \text{REGION_NE} (0.76)$$

LPG Model 2

$$\text{LPG_RU} = -128.9 (-5.49) - 0.36 \text{LN_LPG_P_RU} (-0.09) + 0.18 \text{ROAD_DENSITY_RU} (0.49) + 18.6^{***} \text{LN_PC_NSDP} (5.77) + 0.02 \text{F_LITERACY_RU} (0.19) - 44.67^{***} \text{LOCATION} (-10.38)$$

LPG Model 3

$$\text{LPG_RU} = -144.6 (-5.88) - 1.4 \text{LN_LPG_P_RU} (-0.35) + 0.08 \text{ROAD_DENSITY_RU} (0.23) + 15.9^{***} \text{LN_PC_NSDP} (4.86) + 0.62^{***} \text{F_LITERACY_RU} (5.34) - 2.17^* \text{ROAD_DENSITY_RU*LOCATION} (1.78) - 0.57^{***} \text{F_LITERACY_RU*LOCATION} (-9.25)$$

Proportion of households using LPG as primary cooking fuel is regressed on a set of explanatory variables and results are reported from three most appropriate panel models: one state and two rural-urban. In case of the state model for LPG (LPG-Model 1), LPG_S is regressed on subsidized LPG price, density of distributors, per capita income, female literacy rate and the rate of electrification. Four regional dummies are also included in the model. Results of LPG-Model 1 suggest that only income is positive and significant at 1% level of significance while the rest of the variables are not significant upto 10% level. The dependent variable of LPG-Model 2 is LPG_RU and the explanatory variables are LPG price, separately for rural and urban areas in the state, road density in rural and urban regions, per capita income, female literacy rate for rural and urban areas of the state, and a location dummy indicating whether a particular observation pertains to rural or urban area. ROAD_DENSITY_RU has been taken as a proxy for LPG_DENSITY. Price and road density (and hence density of LPG distributors) continue to be non-significant. The LOCATION dummy is negative and significant i.e. the uptake of LPG is significantly lower in the rural area as compared to their urban counterparts. In LPG-Model 3, income continues to be a positive and significant determinant (at 1% level of significance) while price and road density (and hence density of LPG distributors) continue to be non-significant. In this model female literacy is found to be positive and significant at 1% level of significance implying a positive role of female literacy on decision making in favour of LPG uptake in general. Additionally, the interaction dummy ROAD_DENSITY_RU*LOCATION is positive and significant at 10% level, while the other interaction dummy F_LITERACY_RU*LOCATION is negative and significant at 1% level. The positive sign of the interaction dummy between road density and location shows that building road infrastructure or increasing the density of distributors will be more effective towards penetration of LPG in rural areas as compared to their urban counterparts. The negative sign of the interaction variable between location and female literacy implies that 1% increase in female literacy has greater impact on LPG uptake in urban areas as compared to rural areas.

5.2 Determinants of electricity access for lighting in Indian households

The results obtained from the LPG models are as follows:

Elec- Model 1

$$\text{ELEC}_S = -69.1(-1.0) + 4.84 \text{LN_ELEC_P} (0.87) + 0.32^{***} \text{ELEC_RATE} (2.78) + 6.5 \text{LN_PC_NSDP} (0.7) + 0.61 \text{LITERACY_T} (1.41) + 0.33 \text{ROAD_DENSITY_RU} (0.63)$$

Elec- Model 2

$$\text{ELEC_RU} = -88.3 (-3.26) - 0.36 \text{LN_ELEC_P} (-0.15) + 11.7^{***} \text{LN_PC_NSDP} (3.08) + 0.78^{***} \text{LITERACY_RU} (3.63) - 0.37 \text{ROAD_DENSITY_RU} (-0.72) - 6.89 \text{LOCATION} (-1.36)$$

Elec- Model 3

$$\text{ELEC_RU} = -71.3 (-1.59) - 0.87 \text{LN_ELEC_P} (-0.26) + 11.3 \text{LN_PC_NSDP} (1.59) - 0.20 \text{LITERACY_RU} (-0.26) + 0.21 \text{ROAD_DENSITY_RU} (0.33) + 9.11^* \text{ROAD_DENSITY_RU*LOCATION} (1.84) + 1.60^{***} \text{LITERACY_RU*LOCATION} (2.48)$$

*significant at 10% level of significance; **significant at 5% level of significance; ***significant at 1% level of significance

Figures given in the parenthesis () are the t values.

To understand the determinants of access to electricity for lighting, proportion of households using electricity as primary fuel for lighting is regressed on a set of explanatory variables. The results obtained from one state model (Elec-Model 1) and two rural-urban models (Elec-Model 2 and 3) have been reported. FE panel model is found to be most appropriate for Elec-Model 1 and 3 while RE model is most appropriate Elec- Model 2. In Elec-Model 1, ELEC_S is regressed on average state level subsidized electricity tariff for domestic sector, rate of electrification, per capita income, literacy rate and road density. In this model, only the rate of electrification is found to be significant (at 1% level of significance) i.e. higher availability leading to higher access to electricity. However, affordability related factors such as income and price are not found to be significant in the model. Next, the rural-urban models are estimated. The dependent variable is ELEC_RU. Since the observations are separated for rural and urban areas for each state, the variable ELEC_RATE capturing the rate of electrification has been dropped as it has no implication for the urban entries. In Elec-Model 2, the explanatory variables LN_ELEC_P, LN_PC_NS DP are similar to Elec-Model 1 while LITERACY_RU and ROAD_DENSITY_RU have separate observation for the rural and urban areas of a state. Additionally, the LOCATION dummy has been incorporated to understand the difference in access in rural and urban areas. In this model, LN_PC_NS DP and LITERACY_RU are found to be positive and significant implying that increase in income and literacy – both will lead to increased access to electricity. One interesting observation in the model is that the location dummy is not significant implying the rural areas are not far behind the urban areas in India with respect to access to electricity for primary lighting fuel. Elec-Model 3 has the same explanatory variables as Elec-Model 2 only with the difference that the LOCATION dummy has been dropped and two interaction dummies: ROAD_DENSITY_RU*LOCATION and LITERACY_RU*LOCATION are added. While LITERACY_RU*LOCATION is found to be positive and significant at 10% level of significance, the other interaction variable is found to be significant at 1% level of significance. The positive signs of the interaction terms between location and literacy rate/road density suggest that similar increase in literacy rate/road density in rural area will have greater impact on electricity uptake in rural areas as compared the same increase in urban areas, which is nothing unexpected.

6. Conclusion and policy implication

The paper started with the question about whether availability and/or affordability play a role in the uptake of electricity and LPG in the country. Creation of supply infrastructure i.e. increase in availability is definitely a major determinant of access to electricity, but the same is not true for LPG.

On the question of affordability while subsidized tariff remained to be a major policy intervention to make electricity and LPG affordable in India, the results of this study find that variation in price incentive is not a major source of variation in access— neither for LPG, nor for electricity. This type of price-inelastic demand at a lower level of consumption has significant policy implications, especially for LPG. To understand price-inelastic demand for LPG, one has to take a closer look at the inherent lack of flexibility in packaging of LPG for household use in the country. In India, majority of household supply of LPG comes in the form of a 14.2 kg cylinder and non-subsidized price is roughly in the range of INR 500 – 800 per cylinder. Therefore, unlike electricity, the consumer has to incur this ‘prepaid’ cost as and when the cylinder is refilled. In the short term, policies to ensure payments for LPG on an installment basis, especially for the poorer households, will bring flexibility in use and make the fuel more affordable. In the longer term, gas pipelines could be a solution, where consumers are free to decide their level of use at each point and pay accordingly. Similar to LPG, electricity for the household in India is also highly subsidized, be it supplied by the state boards or by private utilities. But results suggest that tariff difference across states is not relevant to understand the difference in access. Moreover, while the removal of first cost barrier is directed towards the poorer households, the degree of subsidy on tariff is not targeted. As a result, this tariff-based subsidy policy tends to be regressive with richer households benefiting the most from the lower prices.

These results should be seen in the larger context of the other goals under SDG 7 i.e. increasing renewable energy share in the energy mix and enhancing energy efficiency. This is so because after achieving universal energy access for LPG, the next step up the energy ladder would be the use electricity for cooking. The access to electricity both for lighting and cooking is an important medium-term goal which is expected to lead up to the final goal of sustainable and clean energy. In this context India’s ambitious renewable energy target of producing 175 GW by 2022 will have implications not only for energy access but also for renewable energy and energy efficiency.

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Analysis of Brazil's funding structure designed to meet the Sustainable Development Goal 7 targets

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SUMMARY

The present study presents a summary of the results, referring to the energy sector, of the final product report of the National Implementation Project BRA/11/022 - technical support for the preparatory process for the United Nations Conference on Sustainable Development - Rio + 20 and development of its results, related to Outcome 7: Conjunction Analysis on Sustainable Development Goals (SDG) and effectiveness of public, private and mixed funding structures for the promotion of improved sustainable development, coordinated by Young *et al.*, (2108). We find that despite the predominance of the generation of energy from renewable sources, projections indicate that compliance with SDG 7 - "Ensuring reliable, sustainable, modern and affordable access to energy for all" - is threatened. Thus, in addition to the conjunction analysis, we suggest alternative solutions to improve current sources of financial resources, focusing on the effectiveness and efficiency of the selected mechanisms, and identify new funding sources to cover the financial gaps to meet the SDG 7 targets.

1. INTRODUCTION

The proposal to meet the goals of SDG 7 in Brazil is aligned with the objectives of its Nationally Determined Contribution (NDC), with exception of the point related to energy efficiency¹¹. In its NDC, Brazil committed to reduce greenhouse gas emissions by 43% of 2005 levels by 2030. The energy sector has received special attention since it is responsible for about a third of Brazil's polluting emissions. It was established that, by 2030, the Brazilian energy portfolio should have a 45% share of renewable sources. Of this amount, the share of sustainable bioenergy should reach 18%. The electricity sector has received specific targets: to expand the share of renewable energy (in addition to hydropower) to at least 23% of the electricity portfolio and achieve 10% of efficiency gains in the electricity sector by 2030 (BRASIL, 2016).

The present work focus on the financing of actions developed for the achievement of SDG 7 - "Ensure reliable, sustainable, modern and affordable access to energy, for all". We examine ways to improve current sources of income and look for new sources of financing to cover the financial gaps to meet the goals of SDG 7.

Given the focus on environmental issues, the relationship with funding and the existence of metrics with definition problems, for this study we selected the SDG 7 goals, adding to the analysis goal 12.c, which addresses rationalization of inefficient subsidies to fossil fuels. Thus, the topics covered are:

- Universal access to energy (goals 7.1);

¹¹ While goal 7.3 of the ODS talks about doubling the overall rate of energy efficiency, encompassing all sectors, Brazilian NDC aims for much more timid energy efficiency gains and refers only to the electric sector.

- Research and increase the presence of clean and sustainable energy sources in the energy matrix (goals 7.2);
- Improving energy efficiency (goal 7.3);
- Reduction/cutting of subsidies for fossil fuels (goal 12.c).

In addition to this introduction, this work contains four more sections. Section 2 presents the methodology. Following, section 3, presents the investment needs for the achievement of the ODS 7 targets and their expected investment forecast. Section 4 will focus on the need to improve existing forms of funding for programs that collaborate to meet the goals of ODS 7. To close, section 5 presents some alternative proposals for funding mechanisms and other incentive mechanisms which have already proven to be efficient in other energy markets in the world and that are potentially replicable in Brazil. Following is the conclusions on Brazil's achievement of SDG 7 targets.

2. METHODOLOGY

In order to proceed with the “Conjuncture Analysis on Sustainable Development Objective (ODS) and effectiveness of public, private and mixed funding structures for the promotion of improved sustainable development”, we first examined its alignment with the objectives of its Nationally Determined Contribution (NDC).

Following the presentation of the metrics and targets to be achieved for compliance with Agenda 2030, we elaborated a survey of the public, private and mixed resources spent on initiatives related to SDG 7 through 2017. Next, we estimated the necessary financial resources available and missing to reach the targets by 2030. The transition to full compliance with ODS 7 targets was modelled with a gradual increase in expenditures for its compliance. It was considered that the path of necessary expenditures grows at a constant rate, until its full achievement in 2030. This corresponds to an exponential growth in the estimated resource requirements during the period 2018-2030, taking as its starting point the expenditure incurred in 2017 (Young et al., 2018).

The available databases make it difficult to map the initiatives financed by private resources in Brazil due to the absence of information aggregation systems, aggravated by the fact that private companies are not very likely to open their data by confidentiality criteria or fear of the reaction of competitors or regulators. The information is also dispersed and imprecise in the case of actions financed by private non-profit agents. In the public sector, however, this information is more organized and is publicized in the Integrated System of Financial Administration of the Federal Government, which records centrally the movement in the single account of the Treasury with the Central Bank; and the Integrated Planning System (SIOP), which presents the processed budget and provides free data on official budgets per year, by source of revenue and stage of expenditure (Young et al., 2018).

The scenario considered for federal public spending takes into account the fiscal austerity established by Constitutional Amendment n. 95 enacted in 2016, which freezes federal expenditures at the levels in the referred year. Therefore, federal expenditures approved in the Budgetary Law of 2017 will remain the same until 2030. Projections of values are always referenced to 2016 prices, using the Implicit GDP Deflator of the Brazilian Institute of Geography and Statistics (IBGE). In this scenario, state and municipal investments should follow the same federal trend, maintaining fiscal austerity at the 2016 level, given the dependence of these entities on the Union's appropriations and financing. Private investment should grow at an average rate according to the GDP growth trend. GDP was projected until 2030 at a growth rate of 2.5% per year, which is slightly higher than the historically perceived average growth rate in Brazil between 2000 and 2017 (2.3% per year).

All the projections illustrated on the figures presented in this work were elaborated with the previous assumptions and used data from EPE (2017); AIDDATA (2017), MPOG (2015;2014); SIOP (2018). For detailed data information and calculations refer to YOUNG, *et al.* (2018).

3. Evolution of indicators, allocated resources and investment projections required to achieve the SDG 7 targets through 2030

This section presents the investment needs for the achievement of SDG 7 goals. The results are presented, divided into the first three themes, as listed in the chapter introduction.

3.1. Goal 7.1 - “Ensure universal, reliable, modern and affordable access to energy services by 2030 “.

According to IBGE (2017, PNAD, 2011-2015), in 2017, 99.7% of the Brazilian population had access to electricity. The remaining 0.3% are mostly families that are mainly located in rural areas with a low Human Development Index (HDI), characterized by low demographic density and difficult access. In these remote regions, the supply solutions may be autonomous due to the high costs of interconnection to the National Interconnected System.

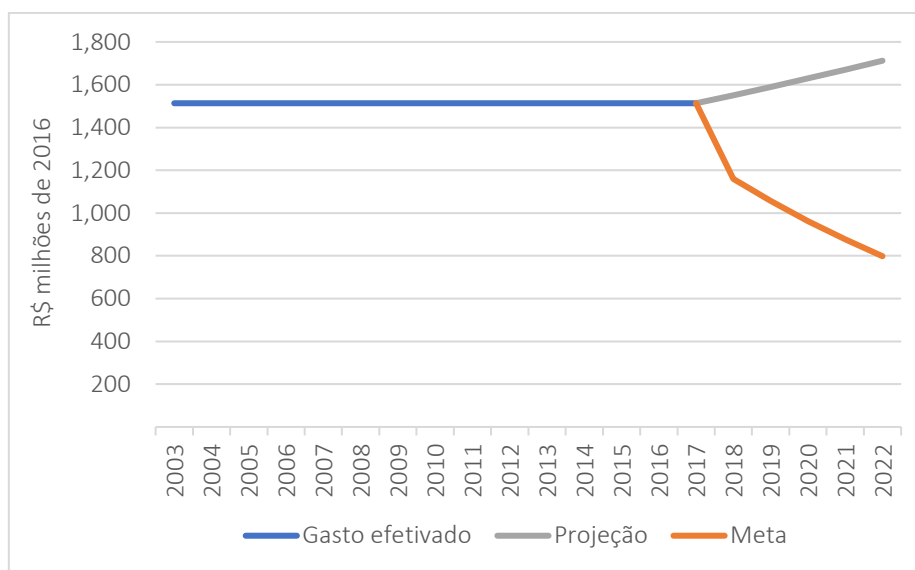
The high costs, coupled with the technical and logistical difficulties associated with the universalization of access to electricity, motivated the recent extension of the Light for All Program, launched in 2003, from 2018 to December 2022 (EBC, 2017). It is estimated that there are still 300,000 new connections to be made, with an investment demand of around R\$ 3.7 billion. As the Light for All Program has been extended, it is hoped that there will be the necessary funding and, thus, the goal of universalization must be achieved.

There is no information in Brazil that reveals whether the origin of the energy used by the population is from a fossil or a renewable source. Thus, the performance of the indicator "percentage of the population with primary access to clean technologies and fuels" is more strongly related to the performance of macroeconomic variables (income elasticity) than to sectoral policies guaranteeing physical access to fuels and clean technologies.

According to IBGE (2018), in Brazil, the domestic use of fuels is only statistically relevant for cooking. If the economic crisis is associated with cuts in social programs aimed at financing energy expenditures by the low-income population, there will be great vulnerability of physical accessibility to clean energy sources and thus a threat to the achievement of the goal. It should be remembered that energy poverty has not been eliminated. Lower-income households often have access to both modern forms of cooking (natural gas and electricity) and rudimentary forms (firewood). With the economic crisis, just between 2016 and 2017, there was an increase in firewood consumption in all regions. In the North, the increase was 16% (239,000 households) and, in the Southeast, 13% (244,000 households) (IBGE, 2018).

In view of the constraints encountered, it is not possible to specify an amount of investment that would make it possible to achieve goal 7.1, based on the indicator "percentage of the population with primary access to clean technologies and fuels". However, the trend observed by the indicator "investments required to universalize access to electricity" indicates that the target should be reached by 2030 as shown in Figure 1. Nonetheless, we must remember that energy access doesn't guaranty its affordability.

Figure 1: Estimate of available resources and gaps to meet target 7.1 (relative to the indicator "Investments required for universalizing access to electricity"):



Gasto efetivado = Realized Expenditure ; Projeção = Projection; Meta: Goal
 Source: De Castro *et al.*, 2018

3.2. Goal 7.2 - Substantially increase the share of renewable energy in the global energy matrix by 2030.

The indicator "participation of renewable energies in the Internal Energy Supply (OIE)" related to goal 7.2 is of simple observation. In contrast, the estimation of the investment to be made in order to achieve the goal is complex. The necessary expenditure/investments differ radically depending on the different composition and locality options of the energy supply.

According to the Ten-Year Energy Plan - PDE 2026 (EPE, 2017), significant investments will be required to meet the needs of the Brazilian energy sector, as can be seen in table 1. Of the investment predicted by PDE 2026, contrary to what it preaches the goal 7.2, most of it goes to fossil fuels.

In fact, 71.4% of the investments planned for the expansion of energy supply are concentrated in the oil and gas sector. There is also an important participation of already competitive renewable energy sources. In addition, the investment forecast assumes important growth of ethanol demand, which reduces the pollutant emissions associated with combustion engines. As we also can see in table 1, if PDE 2026 projections are confirmed, all these goals shall be achieved.

Table 1: Follow up of Brazilian NDC commitments x projections PDE 2026:

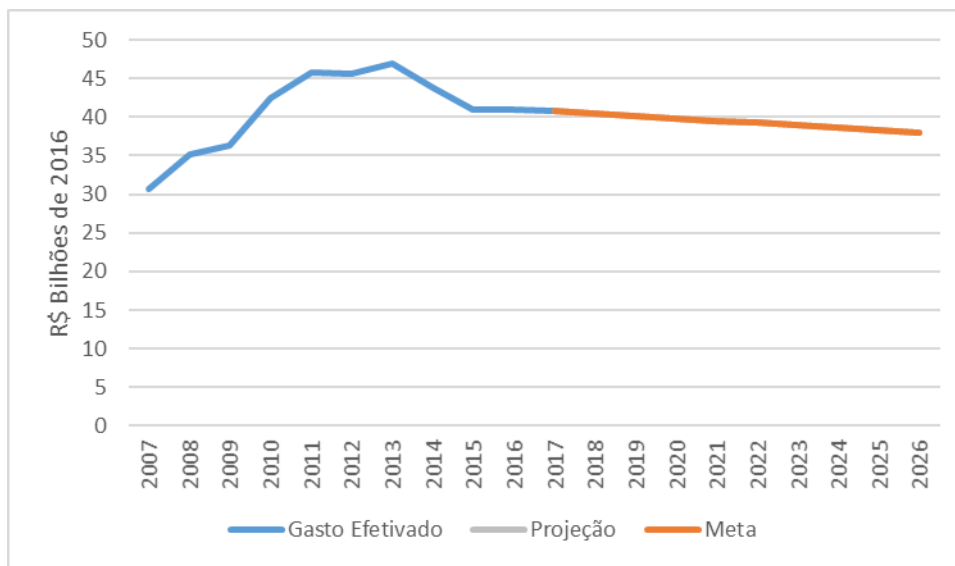
Indicators		NDC	PDE 2026
		Year of reference 2025	
Energy Efficiency	Electricity	8%	4%
Electricity	Share of wind, solar, biomass, including DG and self-production	23%	23%
	Share of hydroelectric energy	71%	71%

Electricity portfolio	Total share of renewables, except hydro generation	23 a	35%
	Share of bioenergy	18%	20%
	Total share of renewables	45%	49%

Source: Adapted from *Plano Decenal de Energia 2026* (EPE, 2017).

Therefore, it is valid to state that the investment foreseen will be sufficient to comply with the scenario presented in PDE 2026, which in turn is in line with the Brazilian NDC. To reach goal 7.2 it will required an investment of R \$ 394 billion by 2026, and, according to PDE 2026, these this will be provided both by the federal government and by private economic agents. Figure 2 shows the evolution of indicator 7.2.

Figure 2: Estimation of available resources and estimation of gaps to meet the goal 7.2:



Gasto efetivado = Realized Expenditure ; *Projeção* = Projection; *Meta*: Goal
Source: Young *et al.*, 2018.

3.3. Goal 7.3 - Double the overall rate of energy efficiency improvement by 2030

Brazil has established as its 7.3 goal the need to increase energy efficiency at an annual rate of 2.6%, corresponding to double the overall rate of improvement in energy efficiency (1.3% per year), estimated in 2009 -2015, by the WEC (2016), measured in terms of energy intensity (ratio between primary energy and GDP). This indicator is also adopted by the document "Tier Classification for Global SDG Indicators" (INTER-AGENCY AND EXPERT GROUP ON SDG INDICATORS, 2016). However, there is strong criticism of its use, since it is considered inadequate to identify efficiency gains in energy use, as it also incorporates changes in the structure of the economy, in economic and population growth, for example (CIVIL SOCIETY WORK GROUP FOR AGENDA 2030, 2018, p.35). Despite these critics, the indicator is considered as the basis of the analysis because of the official recommendation for its use, but it is not commonly used by the researchers on the field, to the point of not having its global methodology defined (IBGE, 2018).

Brazil's NDC proposes to increase energy efficiency by only 10% in the electricity sector, which is quite modest compared to target 7.3, which speaks of doubling energy efficiency in all sectors. For this reason, unlike the previous sections, the Brazilian NDC goal cannot be used as the basis for goal 7.3 of the ODS.

The investment required to meet target 7.3 is extremely difficult to estimate since energy efficiency potential can be estimated by autonomous growth for several factors, but there are no indicators that directly relate the level of investments in the sector and the efficiency gains achieved.

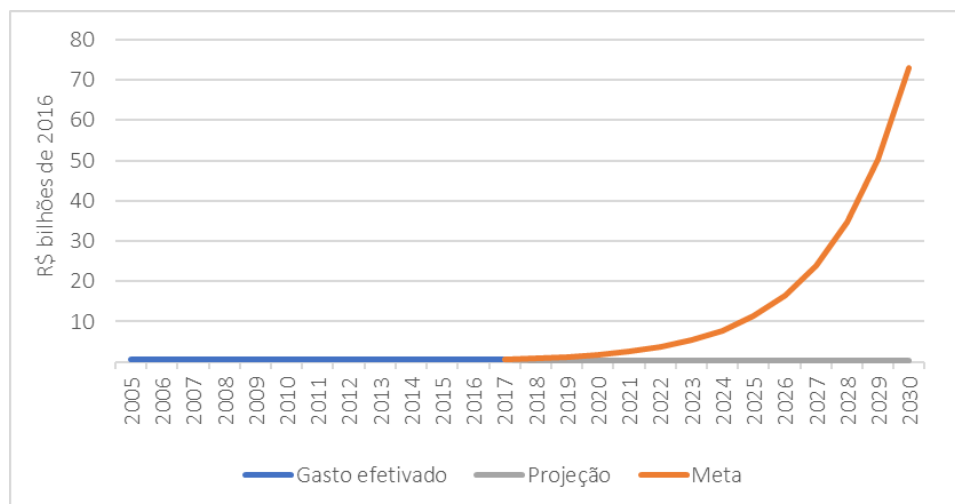
Brazil is well behind the global average, and even Latin America, in terms of improving energy intensity. Between 2000 and 2015, while the world average of energy intensity fell by 21%, in Brazil, this ratio increased by 4.6%. The contrast is even larger when compared to the European Union (23.8% reduction) and the main emerging economies (intensity in China fell by 34.6% and India by 31.9%). The data show that the worsening energy intensity per unit of output puts Brazil against global trends, and that it is fundamental to reverse this trend so that the country advances in Agenda 2030.

Despite the importance of the problem, budget expenditures with energy efficiency actions are not significant. Most public actions are financed through extra budgetary resources, collected through sectoral taxes, which are not included in the government official budget expenditures (SIOP). Investments via extra-budgetary resources are carried out through energy efficiency incentive programs and regulated by ANEEL, within the framework of PEE and PROCEL. Accordingly, Law 9,991 of 2000, amended by Law 13,280 of 2016, established that public utilities should allocate 0.5% of their net operating income to actions that promote energy efficiency gains. Of these 0.5%, 0.1% goes to PROCEL, the main energy efficiency command and control incentive program in force. The other 0.4% is earmarked for the Energy Efficiency Program (PEE).

Based on the historical series of Brazilian energy intensity, raised through the National Energy Balance 2017 (EPE, 2017), and in the extrapolation to 2030 of the energy intensity projection data available in PDE 2026 (EPE, 2017b), in order to meet the target set in goal 7.3, the growth rate of the Brazilian energy intensity should be 2.6% .a. in the period 2015-2030 - higher than the projected GDP growth in the period (2.5% a.a.). To follow the international benchmark the primary energy supply should be reduced in relation to 2015, not expanded.

The projected investments in the baseline scenario for the increase in energy efficiency were estimated at R\$ 7.45 billion (annual average of R \$ 573 million). This amount is well below the amount of R\$ 232.9 billion, estimated as necessary to achieve the desired goal. The difference to the estimated value for reaching the target is approximately R\$ 225.7 billion, distributed over time according to a constant growth rate (Figure 17).

Figure 3: Projection of available resources and financing target for energy efficiency



Gasto efetivado = Realized Expenditure; Projeção = Projection; Meta: Goal
 Source: Young *et al.*, 2018

3.5. Reduction/cutting of subsidies for fossil fuels (Goal 12.c)

There is a significant amount of tax exemptions within the federal government tax structure, and the fossil fuel industry has been particularly privileged in this regard. An example is the suppression of the CIDE (Intervention Contribution in the Economic Domain), incident on the importation and commercialization of petroleum and its derivatives, natural gas and its derivatives, and ethyl

alcohol. Such a tax burdened the price of gasoline and thereby made ethanol more competitive, contributing to the increased share of renewable fuel. Over time, the aliquots dropped sharply, to the point that current levels levied do not affect the demand for fossil fuels in favour of biofuels.

The main tax exemption granted to the oil and natural gas sector is known as REPETRO - Special Customs Regime for the Export and Import of Assets Destined for the Research and Development Activities of the Oil and Natural Gas Reserves. REPETRO is the result of the composition of three suspensive customs regimes: i) Drawback; ii) Exports with fictitious output; and (iii) temporary admission.

This tax incentive has been especially relevant to the oil and gas market, and accounts for approximately 23% of all customs tax breaks in Brazil, between January 2005 and December 2015, for the Brazilian Federal Revenue Office (RFB, 2016).

These imports are exempt from various taxes applied to other sectors and contribute to increase the competitiveness of fossil fuels and, as a consequence, undermine the achievement of goal 7.2 regarding the increase of the share of renewable energy in the Brazilian energy matrix. Initially planned to last until 2020, REPETRO was extended until 2040, with the edition of MPV n°. 795/2017. The impact of this fiscal waiver was estimated at R\$ 30 billion in three years. In all, considering the various pre-salt fields, the tax waiver caused by this measure can reach R\$ 1 trillion (LIMA, 2017).

Thus, Brazil, instead of complying with goal 12.c, adopts contrary fiscal policies, making it impossible to fulfil the proposed target. It is noteworthy that non-compliance with goal 12.c affects negatively the achievement of all SDG targets. The package of subsidies agreed to fossil fuels represents a loss of revenues that could be used to finance programs related to meeting other targets. In addition, they provide gains in competitiveness for fossil fuels and hinder the entry of greater participation of renewable energies.

4. Improvement of existing financial mechanisms to achieve SDG targets 7

As we have showed, the targets 7.3 and 12.c are probably not going to be met by 2030. These goals are interrelated, as fossil fuel subsidies discourage advances in energy efficiency. This section seeks to discuss improvements in mechanisms aiming at the overall improvement of energy efficiency.

With respect to energy efficiency gains, Nascimento (2015) observes that there was a sharp drop in investments made by PROCEL from 2013 onwards, due to regulatory changes. The energy efficiency incentive policies have brought significant gains to the industry, without significant costs, as they are the result of the regulation of minimum levels of equipment efficiency and investment obligations destined for this purpose. Continuing this strategy, the range of products that have minimum efficiency standards controlled and/or receive the certification of the PROCEL seal is being expanded.

In general, the impacts of energy efficiency measures are concentrated in the distribution level of the electricity sector. In Brazil, this issue calls for special attention due to its regulatory framework that presents a "structural contradiction that discourages gains in energy efficiency", as ANEEL, the Federal Independent Regulation Agency, states in a recent technical note (ANEEL, 2018). Law No. 9,991, of 2000, obliges the electricity distributor to collect resources from consumers and to invest 0.5% of its revenue in energy efficiency projects. At the same time, tariffs are regulated under price cap model. In this way, the Utility is the protagonist in the execution of a public policy that compromises its own revenue. Therefore, one cannot expect it to strive to exceed its minimum obligations.

It is necessary to compensate for the impact of revenue loss related to consumption reductions promoted by efficiency gains or change utilities business model. The reform of the institutional organization of the Brazilian electricity sector that is under discussion may address this issue. In

parallel, ANEEL has been discussing new energy efficiency incentive mechanisms that can be adopted with the regulatory framework currently in force, such as energy efficiency auctions.

With regard to the reduction of subsidies and fiscal incentives for the fossil fuel industry, it depends directly on the political will of the government. The industry calls for a thorough tax reform that reflects the polluter pays principle. Here the reverse is true: the polluter receives incentive instead of penalties. Incentives for fossil fuels, rather than regressing, have made significant progress. As the sector's pace of activity increases, the macroeconomic impacts and distortions of competitiveness between fossil and renewable sources are the reverse of what should be observed in an economy pursuing a sustainable development.

5. New funding mechanisms to achieve ODS goals 7

There policy instruments designed to encourage energy efficiency. Of particular note are the financial instruments capable of leveraging the promotion of efficient services and products through the adhesion of companies to the ISO 50.001 norms, the conduction of auctions or White Certificates, and, finally, Utilities regulation improvement to encourage them to adopt projects to promote efficiency in their services, without harnessing their revenue.

Standard 50.001 specifies the energy management system requirements under which an organization can develop and implement an energy policy and establish objectives, targets and action plans that take into account legal requirements and information on significant energy use.

For the reduction of electricity consumption, ANEEL (2018b) proposes the adoption of an auctioning mechanism where the auction organizer defines the amount of consumption to be reduced and the time interval in which it is to be carried out. The agents interested in participating must compete for the lowest price through different portfolios of projects to reduce energy consumption. The Agency is working on a pilot project to be realized in Roraima that should predetermine the methods of measurement and verification according to the typology of actions with the possibility of replicating the auction in other states (ANEEL, 2018b). If the project succeeds, energy efficiency could be treated as an energy resource embedded in energy planning, competing in auctions with power generators.

6. Final considerations

Through this research we were able to analyse the evolution of selected indicators but not capable of presenting a detailed evolution of the funding sources for the achievement of SDG 7 targets. The available databases make it difficult to map the initiatives financed by private resources in Brazil. Moreover, despite progress on public transparency several actions pursued to the attainment of SDG 7 are financed with funds coming from extra budgetary expenses, which are harder to be tracked and provide instable source of resources. The information is also dispersed and imprecise in the case of actions financed by private non-profit agents (Young et al., 2018).

Brazil is very close to guaranteeing universal physical access to electricity for all its citizens. There have been important investments in the expansion of electricity grids and also in the diffusion of autonomous electricity generation systems in remote regions, under the Light for All Program. A more complicated point concerns the energy affordability. The simple allocation of subsidies can worsen the already very poor energy efficiency indicators in the country. This is a complex challenge to be explored in later studies.

There is great potential for Brazil to expand the share of renewable energies in the global energy portfolio. However, in both the electricity and the transport sectors, there has been an increasing share of fossil fuels. In this sense, Brazil is one of the few countries where the energy portfolio has been carbonized, going against technological evolution and worldwide concern about climate change.

Decarbonisation and modernization of energy systems bring several challenges that require significant volumes of investment. Brazil shall be able to achieve of its SDG 7 goals, but could certainly have much more expressive results if the points highlighted in this study are addressed.

Finally, concerning the financing of actions that contribute to a greater participation of renewable energies, as well as gains in energy efficiency, there is concern about the failure to meet goal 12.c, regarding the desirable reduction of fossil fuel subsidies. Tax exemptions for this sector have increased significantly, which does not favour biofuels or the adoption of energy efficiency measures.

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Session 7

Tools and evaluations

Are we lost in the ocean of human development? Finding our way through a SUSTAINABILITY COMPASS

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Abstract

Earlier work by the authors has been undertaken to explore how social learning can contribute to meeting sustainability criteria and indicators and thereby support evidence-based decision-making. The Governance Assessment Matrix Exercise (GAME) matrix and tool-kit was developed initially around the scoring of qualitative criteria relating to the Five Capitals model of sustainability. Following an approach consistent with the interpretation of economics as household management further studies have been developed to apply the model to the pursuit of the United Nations Sustainable Development Goals (SDGs).

The research reported in this paper has been undertaken for the Office of the Finnish Prime Minister with the aim to develop an assessment tool that would support the planning and adoption of sustainable innovations (Inno-GAME) that could contribute to the realisation of the SDGs. Initial interviews were carried out with innovative Finnish companies to obtain qualitative data about the relevance of their activities to the SDG themes and sub-objectives. Following a thematic analysis of the data a number of potential measures and metrics were identified and used as inputs for a follow-up participatory workshop. The analysis of the themes and the metrics/indicators led to the development of a provisional 'Sustainability Compass' tool-kit, which is a multi-dimensional competency matrix and associated metrics/indicators for representing the multifaceted characteristics of the SDGs.

This article will be presented in conjunction with a further workshop to be held at DMU, that would replicate and update the previous experiences. The article will contribute to the refining of the participatory process for the sake of sustainability.

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Background and introduction: a tool-kit for participatory and sustainable household management

An earlier paper presented the need for a critical re-evaluation of economics in reference to its original root meaning of ‘household management’ (Sajeva, Mitchell and Lemon, 2018). Historically, ‘economics’, or οἰκονομία (oikonomia), refers to the effective management and allocation of resources for meeting human (as householder) needs. Repositioning economics as household management has helped integrate human and natural systems into an understanding that would contribute to addressing the on-going conflict between human development and sustainability, from both environmental and social perspectives. The model is based on a systemic approach that rejects closed, oversimplified and anthropocentric conceptions of economics that remain limited to the valuation of goods and services according to individual utility and preference, and which isolate human systems from the natural ones upon which they depend.

This paper presents a first attempt at the practical development of a competency matrix that emerged from the earlier theoretical work by the authors (Sajeva, Mitchell and Lemon, 2018). The sustainability compass, i.e. a model and practical tool/process for governance and innovation is focused on providing a learning-based approach for decision making within the context of sustainable development (Jordan, 2008:18; Sajeva, 2016). The compass was developed for a project, funded in 2017 by the Office of the Finnish Prime Minister, with a twofold objective; firstly to support Finnish business in the evaluation and planning of innovation at the international level and secondly to support policy-making for promoting and facilitating the achievement of Sustainable Development Goals (SDGs) of the United Nations.

In order to pursue this objective, the authors proposed a model for innovation competitiveness that is based on a multi-dimensional perspective of sustainability in line with the SDGs. For this purpose, the earlier GAME methodology (Sajeva, 2016) has been adapted as an Inno-GAME for the evaluation of an innovations’ sustainability under the headings of ‘food and agriculture’, ‘energy and materials’, ‘cities’ and ‘health and well-being’. In particular, the earlier GAME methodology, which was developed around the Five Capitals model of Sustainability (Forum for the Future, 2019), was adapted to the SDGs, as dimensions that are able to describe and integrate systems’ complexity.

This paper first describes, in section 2, emergence of the GAME and Inno-GAME framework before reporting on the interviews undertaken with representatives of Finnish companies engaged in key innovative sectors. The paper then outlines, in section 3, the thematic analysis of the interviews which were used as the basis for a participatory workshop leading to the provisional construction of the sustainability compass.

Finally, this paper introduces, in section 4, possible pathways for operationalising the tool more widely.

The Sustainability Compass is currently being further developed in cooperation with Finland’s leading promoter of sustainable business (FIBS) and the Finnish national technological research centre (VTT) in a workshop with FIBS associated companies.

The development of the GAME methodology according to the UN 2030 Agenda



Figure 1. The UN Strategic Development Goals

The 2030 Agenda is defined by the United Nations as a ‘*plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom [...], to realize the human rights of all and to achieve gender equality and the empowerment of all women and girls [...]* and to free the human race from the tyranny of poverty and want and to heal and secure our planet [...] so that no one will be left behind’ (United Nations, 2015).

Agenda 2030 contains non-negotiable elements such as equality and the eradication of poverty in pursuit of sustainable development. Secondly, building upon the Millennium Development Goals it defines 17 SDGs and 169 targets that are considered as indivisible. These are consistent with the earlier GAME methodology, which pursued an integrated and holistic evaluation of the Sustainable Capitals model articulated by Forum for the Future (2019; Sajeve, Mitchell and Lemon, 2018; Sajeve, Sahota and Lemon, 2015; Sajeve 2016)

$$\min x_i \times \frac{\sum_{i=1}^{10} w_i \times x_i}{\sum_{i=1}^{10} w_i}$$

Figure 2. The GAME aggregation formula

The need of an evaluation that would focus on the principle of indivisibility of interacting dimensions was already described in earlier investigation (see Figure 2; Sajeve, Sahota and Lemon, 2015; Sajeve, 2016). In the formula, the variable x is the sustainability performance, earlier expressed by the scores of the GAME, and in the present article referring to metrics for the evaluation of the SDGs. The weight w aims to assign a greater importance to the dimensions that are mostly critical for the realization of SDGs. The formula multiplies the weighted average for the minimum of the values punishing for values that are very low and for great discrepancies between the dimensions. In this way, just one low performing dimension lowers the total evaluation, which guarantees the indivisibility of the different objectives.

The construction of a framework for analysis: the Inno-GAME approach

The 2030 agenda reveals, on the one hand, key sustainability challenges and on the other, new possibilities to improve competitiveness through innovation, on the bases of a virtuous approach that aims at improving people’s lives without compromising natural systems. The purpose of the following analysis has been to identify the key challenges to the creation and commercialisation of innovation in the context of the UN's sustainable development objectives. The analysis has firstly identified key innovation sectors in Finland, which contribute to sustainable development. In order to build a provisional, multi-dimensional evaluation tool, the scope of the analysis was restricted to

the sectors of agri-food, wood-based materials and renewable energy. This allowed for a more concrete definition of measures that directly referred to the SDGs. A twofold perspective of sustainable innovation design and commercialisation was adopted, including future business opportunities. In order to progress towards this evaluation tool two qualitative research activities were undertaken:

- Nine semi-structured case-interviews were carried out with representatives of innovative enterprises of varying size from the three sectors. The choices about the interviewed companies from the three sectors (food, renewables and timber) were made on the basis of recommendations by experts from the Ministry of Employment and the Economy. The choices highlighted the potential for innovation and strengthening the UN's sustainable development and efficiency. The interviews explored how the companies approached research and product development, commercialisation of innovations, internationalisation and supporting policies in relation to the achievement of SDGs.
- A participatory workshop was organised, in which experts and businesses identified the main themes and possible metrics or indicators in support of planning, design and adopting/commercialising sustainable innovation.

A thematic analysis was undertaken for the data collected from each activity. this was aimed at identifying proposals for metrics/criteria to assess the achievement of the objectives, and at identifying the competitive advantages that may emerge through aligning business activities with the UN 's sustainable development goals.

The analysis contributed to the generation of a 'Sustainability Compass' for promoting the development of sustainable innovations in two stages:

- Innovation design directed to the achievement of SDGs.
- Innovation adoption, and commercialisation strategies enabled through cooperation among private and public sectors in pursuit of better performance in terms of the SDGs.

This will be described in more detail in section 3.

Interviews with Finnish companies on sustainable innovation

The interviews of about two hours had a free form structure focusing on four general questions and related sub-issues used as a check-list. The questions focused on:

- 1) the background to a specific innovation and the pathway to its current state;
- 2) the goals set for the innovation and how they linked to sustainable development. This included eliciting the challenges and risks to the innovation, its commercialisation and the possible use of public services for that purpose;
- 3) the future vision for, and potential of, the innovation for the realization of SDGs.

The more detailed structure of the research questions is reported in Annex I.

Participant companies (see Table 1) were assured that although findings would be published all data would be confidential and participants anonymous. The data in the table below was authorised for publication.

Company (initials)	Innovation	Description of innovation
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AM	Water purification method	The reagent developed purifies the process and waste waters of industry out of soluble metals. The main users of the method are mining companies, community water treatment plants and the services of sanitation of drinking-water of developing countries.
F	Business model for solar energy production	A three-stage business model adopted in India. The company develops and builds the solar energy production site and after that sells to an investor the majority share of the site. The company provides the use and maintenance of the site with a long-term contract.
LG	Construction value chain	The company has focused on improving the productivity of construction. The company controls the construction process from planning to the finished building. Construction solutions are based on modularity and adaptability of buildings.
MW	Open Source Wood initiative	An internet platform where designers can upload their blueprints for architects and builders to use. The initiative aims at increasing the use of wood in cities by sharing information.
N	Production processes for biodiesel and bioplastics	Technology for cleaning impurities out of waste and residues. Any sort of oils or fats can be used as raw material. After cleaning, waste and residues can be processed into biodiesel and bioplastics.
SoS	Underground Wireless Earth Monitoring System	The system is based on sensors that are buried in the soil. The sensors send metrics on the moisture and temperature of the soil. The online service enables real-time monitoring and maintenance of the soil to avoid over-irrigation.
S	Cellulose based yarn	Technology to produce yarn out of wood cellulose without using chemicals. The yarn can be manufactured into fabric. The fabric is well suited for manufacturing of textiles and clothing.
V	Mineral salt	The product is a mineral salt of dairy milk. It is a by-product of cheese production that is produced when salt is removed from whey. It contains very little sodium and can replace traditional salt without compromising flavour.
Y	Recycled fertilizer	The company has endeavoured to increase the use of the side streams of its production processes. The technology developed allows production that uses recycled raw materials. For instance, a recycled fertilizer for farming and a recycled product for the industry.

Table 1. The interviewed companies and their innovations

Two companies were interviewed about innovation in wood-based architecture and pulp processing. In the agri-food sector four interviews were carried out: one on an innovation relating to healthy solutions, and other two on water purification from fertilisers and other chemicals. Three interviews took place with companies in the energy sector and focused on innovations relating to renewables. In some cases, the company was built as new around the innovation, while in others the innovations were developed by already established companies (mostly big ones).

Many of the innovations were conceived, designed or developed within academic institutions or research institutes and cooperation with these institutions was considered of primary importance by

the respondents for the development of innovations. This cooperation, however, remains more problematic and expensive for small enterprises as universities and research institutes are more inclined to pursue relationships with larger companies. The cooperation is important because researchers are often not ready or prepared for the commercialisation of the innovation process which requires significant management skills and market orientation. While mutual learning between academics and entrepreneurs is important it does not always succeed; often due to the reluctance, mainly of scientists, to share research results.

The interviews revealed that income generated by innovations developed in established companies accounted for a turnover ranging from a few percent to 20 percent, while it often accounted for 100% of those established for the purpose of taking the innovation to market. The bigger companies tend to innovate as an additional source of revenue, to their existing products and services. However, revenue is not an adequate unit of measurement for innovation.

In the majority of companies interviewed, sustainability goals were not considered as core objectives. In some however, SDGs were considered at the centre of their strategy and also used in corporate communication and were taken as a starting point for innovation planning. In a few cases, the development of innovation was based on a recognised global problem and revealed significant business opportunities. In one case of innovation for water purification and recollection of used fertilisers and chemicals, investment in innovation was made with the primary goal of improving the company's resource efficiency; this eventually led to the development of completely novel product.

Public funding and improvement of the business environment in support of innovation

An important objective of the company interviews was to describe business environment that might support innovation; this revealed that almost half of the cases involved the public support in the process. Public funding was central to the innovations around which an entirely new company might be built, and often 'speeded' up the process. With established companies, the role of public funding less significant and often not required at all. One reason for this reluctance to work with public funding was that it was too bureaucratic and self-funding was considered more efficient. In some cases, public funding required further reporting work and in others it was provided initially but not renewed. The latter caused funding problems for the company, even where high-value added innovations were being developed for export markets, on the grounds that they carried too high a risk. Public funding is however often used in preference to private partnerships as a means of retaining control. Involving external partnership funding at an early stage was seen to rapidly decrease the innovation developer's ownership unless the partnership is needed for a specific purpose, such as the provision of raw-materials.

Thematic analysis of interviews

The interviews were analysed to identify the main risks, challenges, actions and metrics for sustainable innovation in each of the selected sectors. This was done by:

- a first transcription of the interviews by a professional consultant:
- a thematic analysis of the text, classified, according to the interviewee's evaluation, as challenge, risk or action for improvement
- the classification of the single arguments raised according to more some general themes, done by the joint work of three researchers.

The results, which are summarised in the following tables (2-4), were then explored with the participants of the subsequent workshop.


 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation					
Proposal of metrics	Quality certification: level and type of measured impact. Maximum level: certification of goal achievement	Resource efficiency: percentage of used resources in relation to the part wasted	Productivity of work, decrease of working time and hardness	Support services: possibility of funding according to criteria	Quality and quantity of cooperation
Action for improvement	Regulation and standardisation of productions (e.g. REACH). Certified products	Smart agriculture and use of water in relation to the specific cultures.	Increase of work productivity and decrease of work time.	Funding and co-creation models for innovation. Foundations and support institutions for achieving cooperation with partners and clients	Efficient cooperation for the achievement of SDGs
Challenge	Lack of knowledge about quality and possible impacts	Circular economy: human-nature systems' integration	Challenging situations of possibly harmful work. Sharing of technological development advantage.	Lack of funding and funding instruments	Problems in partnering, for instance due to bureaucracy
Risk	Signals of scarce quality and related possible harmful impacts	Inefficient use of resources, natural resources decrease	Accidents and harm at work. Inefficiency of impossibility of efficient work.	Lack of innovation due to lack of incentives and funding	Lack of cooperation

Table 2. Example of results of thematic analysis for the agri-food sector




SDG	 12 RESPONSIBLE CONSUMPTION AND PRODUCTION		 4 QUALITY EDUCATION		 17 PARTNERSHIPS FOR THE GOALS	
Proposal of metrics	Environmental reporting, avoided emissions (e.g. CO2).	Principles for resourcing, reporting about origin, certification.	Communication, influence of interest groups	Quality and quantity of continuous social learning	Level of participation into networks and into activities of cooperation for development.	Quality and quantity of cooperation
Action for improvement	Development of production process for minimisation of side effects	Absence of negative impacts from renewable raw-materials origin and value chain, and its transparent communication.	Focusing on exchange of information and advantages of innovative materials. Participation into educational programmes	Simplification of innovation adoption. Development of modular solutions	Enhancement of cooperation and networking, support of all interest groups, simplification of resourcing processes	Platforms for cooperation and social learning, for a simple and effective cooperation.
Challenge	Harmful substances are produced in the production process	Elimination of negative impacts in renewable raw-materials extraction	Risks from the adoption of innovative materials koetaan riskialttiiksi, because of new modes of use and characteristics.		Pienillä toimijoilla ei ole resursseja osallistua tarjouskilpailuihin / päästä markkinoille.	Innovative solutions, unused because of lack of cooperation
Risk	Harmful substances are released into natural ecosystems	Production of negative impacts from renewable raw-materials extraction	Users rely on older products because of being unaware of new ones		Heavy processes for resourcing prevent the use of products.	Overlapping, inefficient use of resources, non-use of existing sustainable solutions

Table 3. Example of results of thematic analysis for wood-based materials

SDG	17 PARTNERSHIPS FOR THE GOALS	7 AFFORDABLE AND CLEAN ENERGY	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	4 QUALITY EDUCATION
Proposal of metrics	Parameters for facilitating the adoption and use of innovative harmful technologies	Networking and cooperation of sustainable innovations	Level of user-friendliness in innovation adoption	Certification for energy sources and their impacts	Funding for innovation
Action for improvement	Regulation in favour of renewable energy	Cooperation in value chains: researchers, investors, developers, distributors, consumers	Product development leading to a simple adoption by consumers	Focusing on scientific evidence and use of waste. Transparent value-chains.	Increasing funding. Specialisation of academic institutions.
Challenge	Renewable technologies cannot compete in absence of supporting policies	Lack of cooperation and understanding in the marketing of the innovation	Difficulties in innovation adoption	Need of large availability of renewable energy sources	Public funding for innovation development tends to be decreased.
Risk	Lack of understanding of non-negotiable renewable solutions	Inefficiency of value-chain, innovation adoption don't succeed	Reliance on older solutions where innovation adoption has elements of complexity	Production of negative impacts from renewable sources or depletion of limited resources.	Decrease in funding and competencies for innovation. Important research areas are not motivating students and researchers. Decrease of specialisation.

Table 4. Example of results of thematic analysis for renewable energy

The proposal of an Inno-GAME competency matrix for innovation evaluation and improvement towards SDGs

The aim of the workshop and the Inno-GAME structure is to initiate a process of dialogue and social learning between experts and policy-makers/stakeholders to define sustainability criteria and ultimately a measurement tool that could support public and private policies for the promotion of sustainable innovations.

Case-interviews summarised in Tables 1-3 provided suggestions for a follow-up participatory process (Figure 2 and 3) which followed the Futures Workshop guidelines of Jungk and Müllert (1987). Three working-groups focused on healthy foods, renewable energy and wood-based materials and participants, including entrepreneurs and expert/academics were asked to suggest the possible challenges in each sector. In this 'critique phase' (phase 1) they suggested possible challenges related to the achievement of the SDGs that the Finnish innovation system can contribute to solving. Phase 2 addressed the risks of failure and possible irreversible or unrecoverable impacts that represent systems failures (e.g. loss of ecosystems or species, or significant harm to of human systems). The suggestions were then grouped into central themes and the GAME process followed to calculate a composite indicator (see Figure 2 and 3) on the basis of the performance level of single metrics/indicators. In the subsequent visioning phase 3, participants suggested criteria for measurements, qualitative or quantitative, that could support innovation planning and indicated improvements towards the achievement of SDGs.

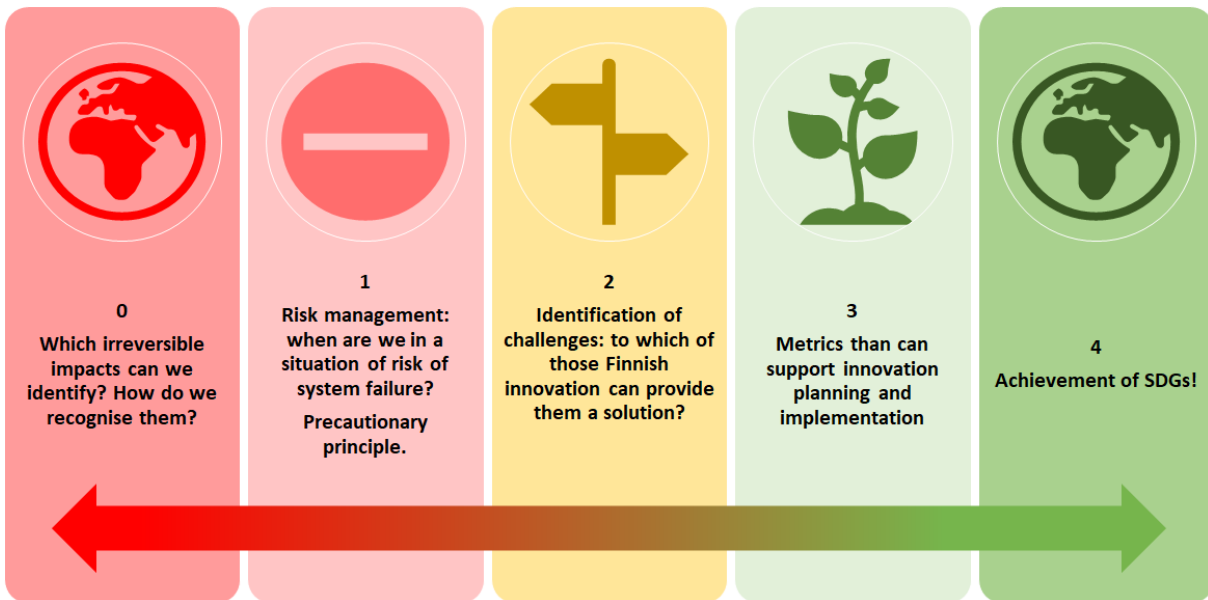


Figure 2. A scheme of the Inno-GAME

Participants agreed about a number of these themes; a process that will be triangulated with input from experts outside of the workshop and for cases outside of the sectors focused on for this exercise.

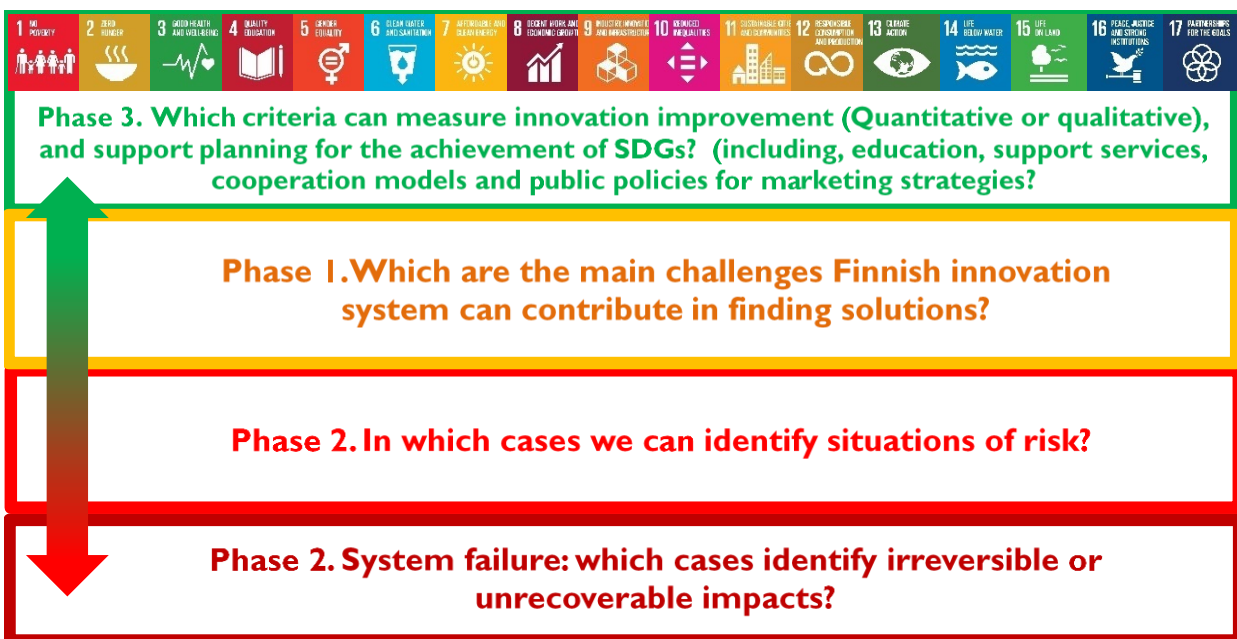


Figure 3 The application of Inno-GAME to the achievement of SDGs for the participatory construction for the Sustainability Compass

The results of the workshop were then analysed according to the themes and possible metrics/indicators, associated to the SDGs. Examples of the outcomes are reported in Tables 5-7.







SDGs	Theme	Metrics proposed for the agri-food sector
	Impact on climate	Temperature variation
		Quantity of substances potentially affecting temperature
		Change in consumers' habits: animal and vegetal proteins ratio
  	Production and consumption related to resource availability	Share of GDP on agricultural sector
		Agricultural production increment and generated value added
		Environmental burden (energy, water, raw-materials materie prime): amount of resources consumed
		Amount of food waste
		Amount of circular economy on the bases of LCA for product/service
		Educational level and offer of education for adult population
	Human health	Amount of food producers
		Number and severity of accidents on the job or sickness cases in the agri-food sector (and related costs)
	Environmental impact	Biodiversity level and amount of theathened species
		Impact produced on air, water and soil
		Land used in agriculture
		Population growth

Table 5. The proposed meters/indicators for the agri-food sector








SDGs	Theme	Metrics proposed for the wood-based materials sector
 	Impact on climate	Use of wood raw-material: amount of carbon captured or released and quality of information for consumers
		Carbon balance: harvested and planted forest ratio
		Renwable and fossil energy replacement ratio
 	Production and consumption related to resource availability	Educational and information level of consumers
		Percentage of harvested forest in a unit of time
		Wood/concrete use ratio in the construction industry
		Amount of circular economy on the bases of LCA for product/service
 	Percentage of sustainable industry and local well-being	Jobs generated by the forest sector at local level
		Percentage of innovative products, such as cellulose replacing plastics or synthetic textiles (also in terms of revenue)
	Environmental impact	Biodiversity level and amount of theathened species
		Impact produced on air, water and soil
		Percentage of forest for production purposes

Table 6. The proposed meters/indicators for the forest and wood-materials sector






SDGs	Theme	Metrics proposed for the renewable energy sector
 	Impact on climate	Taxation of produced CO2, and use of it for supporting renewables, also at small scale
		Tax on estates related to CO2 emissions (energy certificate)
		Creation of individual quotes of CO2 produced and their measurement
 	Production and consumption related to resource availability	Adoption and evaluation of carbon footprint for goods and services
		Ecological scoring to design for a virtuous competition (environmental certificate)
		Level of prices for energy immission from renewable sources also by small scale producers
	Cooperation and public support	Public governance and cooperation
		Expenditure for energy innovation
		Level of cooperation of smaller producers and consumers of renewables

Table 7. The proposed meters/indicators for the renewable energy sector

These results were organised as in Figure 5, which is an example from the much larger excel document where many more indicators are present. This is a first rough vision of what the Sustainability Compass might look like as an IT interactive tool that identifies sectorial themes and indicators and how they perform in relation to one or more SDGs. In the same way each indicator can be used to measure one or more themes related to one or more SDGs and participants can refer to existing indicators or propose new ones. As shown in Figure 6 (numbers are purely indicative) participants can then perform an individual, and or, collective evaluation, according to the indicators existing for each sector.

The Sustainability Compass is formed by two different dimensions as represented in Figure 5 and Table 8, of:

- innovation design, aiming at its improvement in relation to the achievement of SDGs
- innovation adoption, which includes competitive strategies and policies that would incentivise sustainable innovation and create the basis for virtuous competition towards SDGs.

The interviews and the workshop revealed how sustainability pathways require both the recognition of common goals and invariably elements of cooperation between public and private sectors. Governance for sustainability needs common rules of the competition game which are set to avoid jeopardising non-negotiable and evidence-based needs and systems' limits for sustainable virtuous competition, based on the improvement of SDGs related criteria and indicators of sustainability. The best wins and not the worst. Therefore, the construction of the participatory approach includes an analysis of stakeholders involved and the possibilities for:

- the identification of differences and choices, which can determine different goals among different stakeholder groups, to be pursued within the limits of sustainability

- a process of cooperation and agreement about adequate indicators, to progressively build agreement around and common goals, according to more robust evidence about non-negotiable needs and systems' limits

For this purpose, Table 8 proposes a user guide for the Sustainability Compass, in which each actor has got individual roles, strategies and objectives, but cooperates with the others for the achievement of common goals, i.e. the SDGs. The process includes a first phase of the construction and/or updating of the Sustainability Compass (see Figure 5) and a second phase in which the company or the decision-maker can perform a self-evaluation in the pursuit of performance improvement (see Figure 6).

Sustainability Compass User Guide			
Actor	Business	Consumer or expert	Decision-maker
1. Construction of the Sustainability Compass per sector: which metrics or criteria can we use to evaluate the proposed themes? Which other themes can we propose?			
Innovation design	Think about how to design an innovation so that it can improve the indicators related to the themes proposed. Think whether the evaluation of the sustainability of the innovation would require new themes or indicators. If this is the case send a proposal.		
Adoption, commercialisation and support	Design the competitive strategy for the adoption and commercialisation of the innovation through the themes and indicators proposed. Propose new themes or indicators if not present nuovi temi.	Suggest models for markets, governance or public services that can promote more sustainable innovations, according to the themes and indicators. Propose new themes or indicators.	Design market models, governance or public services to promote and support more sustainable innovations, according to the themes and indicators. Propose new themes or indicators.
Cooperation	Propose and design cooperation models in support of more sustainable activities.		
2. Self-evaluation: measure your performance level according to themes and indicators of your sector. If some of them do not concern your activity you can leave them blank by an adequate justification.			

Table 8. The Sustainability compass user guide for business and decision-makers

The 'Sustainability Compass' would need the definition of a participatory approach, as a future activity of investigation which realises:

- sustainable innovation or business operation design and governance.
- a model for and governance of sustainable innovation, that includes incentives, standards (mandatory or voluntary), agreements and other instruments that can set the rules of the competition game, and build the convenience for the single actors, companies and consumers to achieve SDGs.

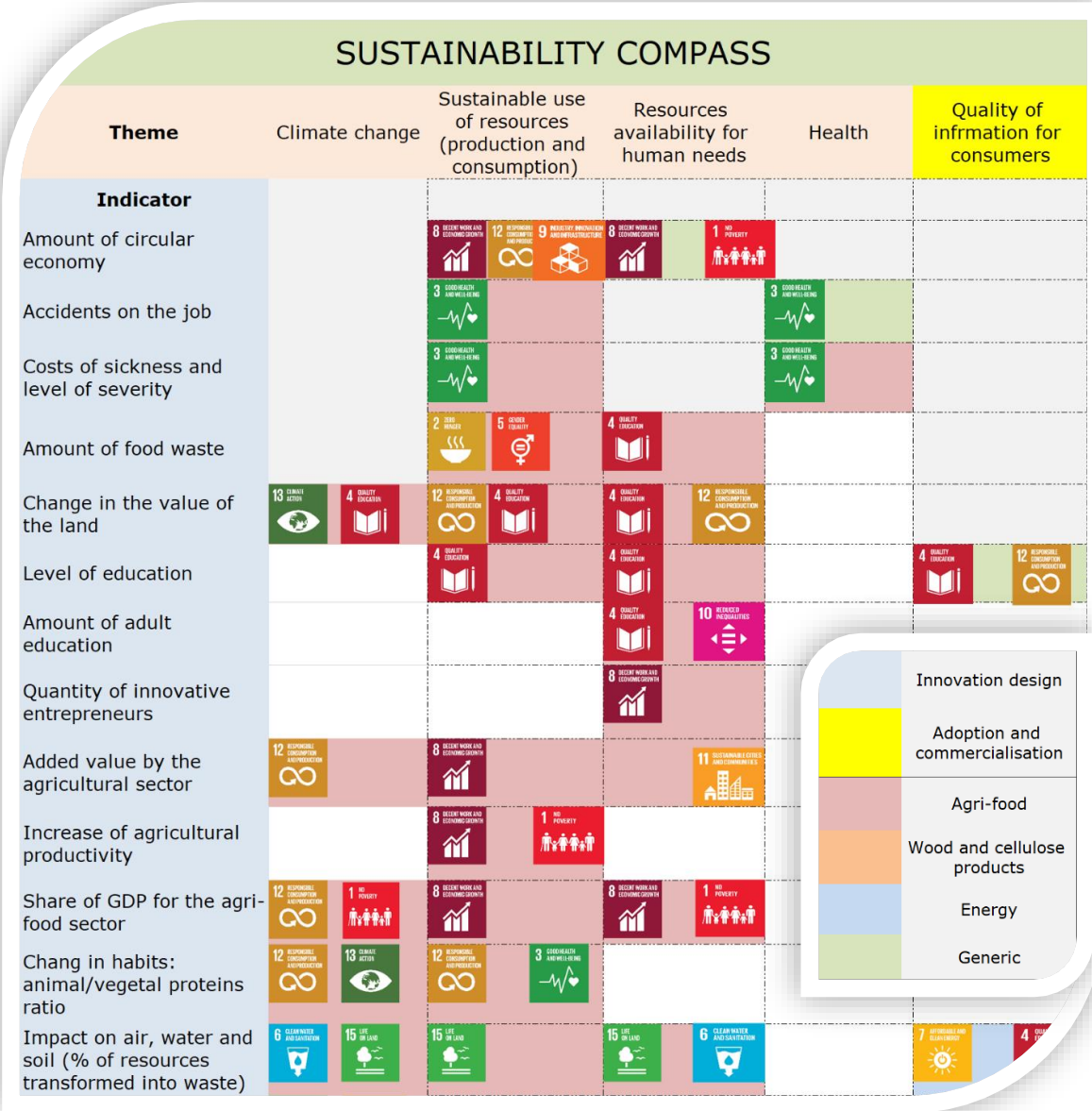


Figure 5. The identification of metrics/indicators for the measurement of performance on SGDs

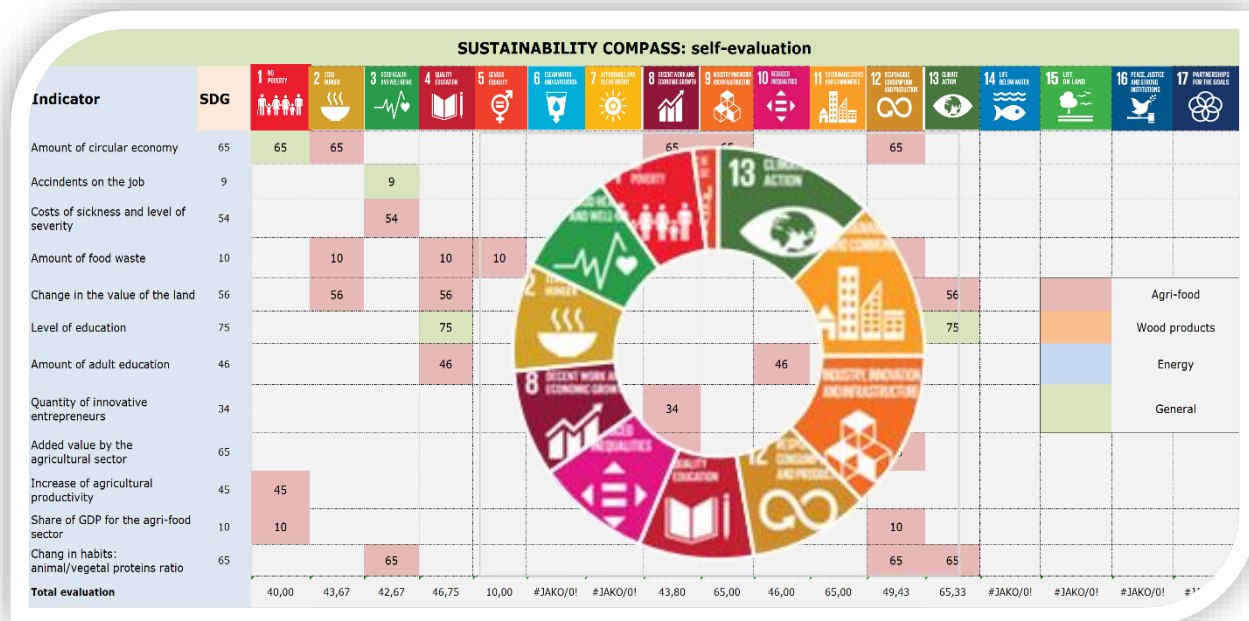


Figure 6 The self-evaluation by the Sustainability Compass

Conclusions and further developments

Besides the determination of single indicators, the exploratory research that underpinned this paper revealed a need for a stronger cooperation and public sector support for the commercialisation of innovation. Indeed, the SDGs themselves seem to be in contrast with more traditional competition strategies which in their attempts to improve productivity can lead a race to the bottom by exploiting social and ecological capital rather than enhancing them through well-being and the responsible use of resources. By contrast, one interview revealed cited an example of a major Finnish company which, thanks to an innovative investment structure, involving more participants, established part of its production in a developing country but instead of profiting from lower costs, offered workers working conditions according to Finnish standards, providing personnel security and well-being to which they were not accustomed in their country. This approach could exemplify the virtuous competition that is discussed in this paper and provides the direction (compass) for companies to move forward by recognising the value of human, social and ecological capital, and growth, as intrinsic to their sustainable process and product innovation.

On the basis of an innovative and heterodox approach of ‘hard economics’ that finds its roots in the concept of ‘household management’ and development as bounded capabilities, this article has described the practical use and implementation of the GAME method for the participatory development of a Sustainability Compass. The tool consists of a competency matrix and multi-dimensional measure of sustainability which is directed at supporting strategic decision-making in its pursuit of the Sustainable Development Goals (SDGs). The Sustainability Compass identifies a future-oriented course for sustainability across the triple bottom line of environmental, social and economic drivers by an evidence-based analysis of systems’ functioning and the determination of metrics for the evaluation of performances in different dimensions (themes) towards the realisation of SDGs.

The Sustainability Compass presented in this paper is at an initial stage. Nevertheless, it is currently being used by FIBS, a not-for profit promoter of sustainable business and developer of expertise in

Finland, in cooperation with VTT, as an application to support FIBS associated companies in understanding the opportunities for sustainable and responsible business and to initiate a virtuous competition that is grounded in sustainable well-being. The cooperation with FIBS and VTT extends the scope of our analysis to all companies' operations, and we consequently reserved our application to the appropriate business sector.

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ANNEX I: the structure of the interviews

BACKGROUND

1. Would you briefly describe your innovation? How did the idea of innovation emerge and how did it progress up to the present?
 - What have been the biggest challenges for commercialisation and why?
 - What was the decisive factor for investing in the development of the idea?
 - What were the critical moments / potential problems of innovation and how were they solved?
 - Has the innovation been developed in accordance with the objectives of sustainable development, and if so, which objectives?
 - Who have been the key actors in the innovation process / ecosystem and what are their areas of expertise? An innovation ecosystem refers to research and product development (R&D) co-operation with the university and research institutes, and a functioning public infrastructure.
 - What kind of cooperation has emerged and with whom? How did it develop?
 - How important has the innovation ecosystem been in creating the innovation? And how important was the innovation ecosystem for its commercialisation?

OBJECTIVES AND SUSTAINABLE DEVELOPMENT

2. To what extent are the UN's strategic goals known to your organisation? To what extent are innovations being developed to achieve them or how has innovation indirectly affected their achievement? Would you look at the table on the next page about SDGs and would you check the aspects that may be affected by the innovation? Would you describe the purpose of the innovation, the general objectives and the extent to which the objectives of sustainable development are integrated into the general objectives of innovation?
 - What goals were set for the innovation when it was decided to start developing a commercial product / service?
 - Which products or companies are the main competitors and what is their market position?
 - What are the strengths of the innovation compared to conventional solutions? What problems does it solve? Can you imagine how much innovation goes beyond the usual solution, in order to achieve the goals?
 - How does the innovation achieve the principles of sustainable development (e.g. environmental, social, human, welfare)? What strengths does it have? What are the key features that make it sustainable?
 - What kind of units / indicators could you imagine explaining the environmental, human, social, infrastructural and economic sustainability of your innovation in terms of how to achieve the UN goals? Environmental sustainability refers to ecological impacts, to human sustainability, to work and well-being effects, to societal sustainability in social structures, to infrastructure sustainability through fixed capital and physical structures.
 - Have you experienced that these sustainability dimensions defined by the SDGs were in conflict? In which case has the improvement of one dimension weakened another dimension?

TRADING AND PUBLIC SERVICES

3. Please, describe the success of the innovation so far and the factors supporting it (marketing, communication, public support, etc.).
- In 2017, how much of the sales of innovation covered your company's turnover? Is it about expanding the core business or developing a new business?
 - How much of the innovative products / services are exported?
 - How can we communicate the sustainability of innovation?
 - Have your organization or products / innovations received a quality or environmental certificate or eco-label (ISO9000, ISO14000 or equivalent)?
 - Has public support been given to innovation? If yes, what funding has been received and how much?
 - How would private and public structures, models and policy measures support the achievement of the goals set for innovation?
 - Have you used public services for commercialization? What have you used and what have been your experiences of using them? Have they supported?
 - How can cooperation between companies and research institutes be promoted / what ecosystems are needed to achieve this goal?
 - How challenging would export abroad be if social models were different or services were missing?

THE VISION OF THE FUTURE

4. Could you describe the prospects and implications of the future of innovation over a period of 5-20 years for the environment, people, society, infrastructures and the economy, especially for the UN's Sustainable Development Goals?
- What kind of positive effects would innovation have?
 - What kind of challenges could innovation cause? Why and how would innovation bring challenges? What challenges / weaknesses / weak signals can be perceived? A weak signal is a small feature or change that may possibly be an alarm that a bigger change might happen in the future.
 - How could these challenges be solved?
 - Have you gone through the risk assessment process? What kind of risks are involved in the innovation and what kind of effects would they cause? Why and how would they pose risks? Do you monitor weak signals in case the risks materialize and cause damage?
 - Is there a need for increased knowledge and training for innovation, technology and processes in order to achieve the goals of sustainable development? Is there a difference between domestic and foreign expertise? Is there still much to learn from abroad?
 - How to develop policy actions and public services (eg Business Finland services) in order to better integrate these innovations and companies in the area. organizations and public organizations and NGOs?
 - What criteria should be used by infrastructure to guide companies towards sustainable innovation? How would ecosystems, models and policy actions support?

- What are the market prospects for these innovations? What is needed to bring these innovations to commercialized export products and services as well as comprehensive solutions? How would ecosystems, models and policy actions support?
- What models and ecosystems would be challenging?
- What models and ecosystems could pose risks?
- What kind of designs and ecosystems would cause similar disappointments?

How could they be avoided?

Is this working? Evaluating complex sustainable community interventions.

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Abstract:

Pressure continues to mount for a radical shift in our *modus vivendi*, especially in the West, but increasingly among the developing nations too. Some planetary boundaries have already been breached by our economic activity, while others come increasingly within scope. The stark criticality of the Anthropocene and its anticipated trajectory will, ironically, likely not be Anthropophilic: that is, the 'age of the human' will, in all probability, *not* be human-friendly. Under conditions which demand effective developmental actions on a short time-scale, and at a local level, evaluating the cost and impact efficacy of such interventions is all the more necessary.

However, endeavours to affect the development of the potential sustainability of a community's trajectory typically engage complex and recursive systems of places, people, policies, and politics, each with histories and path dependencies and with different perspectives on the evaluation process – does it provide guidance and insight to practitioners and community stakeholders and or policy makers or help with the assessment of whether a programme and its constituent project has met its aims? With the Sustainable Development Goals for decent work and sustainable communities (8 and 11 respectively) as a field guide to markers of sustainable living, this paper presents recent evaluative work with a Big Lottery 'Communities Living Sustainably' project from three perspectives: its contribution to the local food and drink economy; its contribution to the realisation of a socio-economic network; and its self-organisation as a site for practitioner and community based learning.

Words: 243

1. Introduction:

In response to the existential and long-term threats arising from society's current inability to act within ecological boundaries the United Nations General Assembly generated seventeen Sustainable Development Goals (SDGs) (United Nations, 2015). Idealistic though these may be, the suite of goals recognises both the interconnectedness of the social-ecological systems within which humanity is an active part and the urgency of the task at hand. These are therefore salient multidimensional metrics against which to monitor progress in learning to live in a more sustainable and resilient way.

The challenge with all metrics however concerns how they are evaluated (Bradshaw, Giam, & Sodhi, 2010). In this paper, using a community-based sustainability project as a case study, we explore three approaches to evaluate the complex dynamics of the project with respect to the local economy, the socio-economic system, and the processes of learning involving the project actors and stakeholders. These multi-dimensional perspectives are located within the broader contexts of SDG 8 ("Decent work and economic growth") and SDG 11 ("Sustainable cities and communities"), and are discussed as prospective evaluation methods for tracking the complexities of systems change. The adoption of a multi-method/ multi-focus patchwork evaluation approach to complex interventions is consistent with recent work being trialled elsewhere (Connelly & Vanderhoven, 2018), and confirms the added value of maintaining multiple perspectives simultaneously.

While the paper is focused on examples of evaluative tools for different aspects of sustainable community projects, it also highlights that practitioners and community stakeholders may not have the same level of interest in monitoring, or the technical skills and time to undertake it, as academics or funding agents. This highlights the importance of aligning monitoring and evaluation with the ongoing delivery of projects and the transfer of this learning more widely.

Following on from this introduction the paper briefly introduces the community-based sustainability project, in terms of its aims and scope, to set the context for the rest of the discussion. Section three introduces the local multiplier method (LM3) for evaluating the economic impacts of inward investments to a geographically bound area. Section four then considers the application of social network analytic (SNA) methods to evaluate the relative resilience and characteristics of a food and drink supply and retail community, while section five reviews the operational and strategic learning generated by the actors and stakeholders involved in the sustainability project. The paper concludes with a reflective review of the challenges and opportunities for evaluating complex and dynamic sustainability projects and programmes and the need for such processes to support project legacy, be transferable and potentially scalable.

2. A case study community sustainability project: Introducing Sustainable Harborough

The case study which forms the context for the methods discussed in this paper was one of twelve Communities Living Sustainably (CLS) initiatives made possible by a 2012 BIG Lottery grant-fund. The Sustainable Harborough project (SHP) was funded from January 2013 to December 2017 inclusive and located in Market Harborough, in the Harborough District of southern Leicestershire. As the responsible senior partner, the Leicestershire and Rutland Rural Community Council (RCC) employed four full time staff members who were assigned to the project. The RCC reported to the BIG Lottery and the project work was steered by a non-legally binding partnership of organisations, including Leicestershire County Council, Harborough District Council, De Montfort University (DMU), edibLE16, and Transition Harborough (the local chapter of the Transition Town network).

The objective of the CLS fund was to test and learn how to help communities engage with living sustainably, to mitigate and to adapt to climate change and to reduce the incidence of fuel poverty. The fund emphasised experimentation on learning what works and does not work in projects whose aim was, and is, to facilitate community-scale changes in sustainable living. DMU was integrally involved with the design, development and support of the SHP's learning capacity, through regular facilitated participatory action research meetings, on-going consultation and access to domain experts. This was made possible by the project's sponsorship of a PhD research candidate located at DMU's Institute of Energy and Sustainable Development and the methods discussed below are based on the primary author's PhD placement work and post-doctoral consultancy.

Sustainable Harborough focused its activities on supporting and enabling the emergence of a local food and drink economy, and engaging businesses in community-owned and invested renewable energy schemes. The project team quickly discovered that, by and large, Harborough residents were less receptive to engagement than businesses, so the majority of the effort on developing specific projects was with the business community. The general public were engaged predominantly through public festivals and events which promoted the key themes. Of the two principal themes (energy and food) developed through the work of the SHP, the local food and drink economic network offered the best opportunity for trialling different evaluation approaches focused on the generation of economic and social capital; these are elaborated on in sections three and four of the ensuing paper. While not a theme *per se*, but given the central focus of the CLS fund on learning what works, the fifth section discusses the meta-learning acquired by the project team and stakeholders as part of a summative review of lessons learned.

3. The economic multiplier effect of an on-line retailer of locally sourced food and drink: An LM3 of edibLE16

EdibLE16 evolved from a Harborough Transition Town idea for a local food hub which, under the auspices of the SHP, became an on-line retailer of locally sourced food and drink. Within this context, 'local' refers to a twenty mile radius around Market Harborough. The business model began with a click-and-collect service, with customers placing orders on a Wednesday and collecting them at the weekend from a space that had been donated to edibLE16 for that purpose. Over time, and with a growing customer base, the business model shifted to both sell a wider range of products and to offer a delivery service.

There is an intuitive sense that buying locally produced food from locally sited retailers is not only healthier due to the shortened distance between field and fork (DuPuis & Goodman, 2005; Kemp, Insch et. al., 2010), but will also have knock-on economic benefits for the participating area (SERIO, 2012; Tregear, 2011). To evaluate the second of these assumptions, the LM3 (local multiplier to the third round of investment/ spend) was recruited and is summarised below.

The LM3 is a tool that adapts the macro-economic theory of multipliers for use in micro-economic circumstances. It is an indicator that tracks how effective an initial investment is with respect to the length of time it remains within a defined economic area, and the amount of additional work that it leverages, and does so to the third round of spending. In practice, this translates to how the initial investment with the organisation of interest (first round or R1) is, in turn, spent with that organisation's suppliers (second round or R2), and the percentage of that income those suppliers spend within the locally defined area (third round or R3) (Sacks, 2002).

For the purposes of evaluating the knock-on economic benefits of edibLE16, the initial investment, whether through grant funding or through customer sales, was assessed using three years of financial business records. The initial investment (sales revenue and grant revenue) constitute the first round (R1). At this point, all investment is inwards to the area, so all R1 is considered 'local'. Afterwards, the second round (R2) was calculated using the transactions of all suppliers that edibLE16 spent money with in order to fulfil customer orders and to maintain itself as a business. R2 is the first point at which the distinction between local and non-local applies. What is outside of the bounded area of economic interest is excluded from the subsequent third round (R3) calculations. It was discovered that R3 posed some methodological challenges because it tracks the amount of spend by suppliers to edibLE16 which themselves also fall within the local and bounded economic area. To acquire this data, suppliers were surveyed for the estimated percentage of income they spent within a twenty mile radius of Market Harborough. Only some of the suppliers surveyed responded with data, which means that there were significant gaps in the data set; the response to this missing data is addressed elsewhere (see R3 a. and R3 b. in Table 1 below and Mitchell & Lemon, 2019).

The findings from this evaluation are nevertheless informative. The LM3 ratio tends to show a strong emphasis across the supply chain in keeping the investment local. LM3 ratios range from values of 0 (zero) to 3, with 0 meaning that there has been a 100% 'leak' of all initial investment outside of the bounded economic area, and a value of 3 meaning that all initial investment has been retained. Ratio values ranging from 1.95 to 2.24 suggests that an initial investment with edibLE16 has proven to be effective, that the initial investment tends to remain within the local economic area, and that the investment is made to do additional work at each round of spending. To determine the 'new' money circulating the economic system, the initial investment is removed from the calculations. For the three years from October 2014 to August 2017, investing £1.00 with edibLE16 can be evidenced to have contributed to the local economic area of Market Harborough by between £0.95 to £1.24 (depending on the method used to manage missing values).

The details of the LM3 calculations are given in Table 1, below.

Table 1. Summary of all LM3 calculations (rounded values). Source: Mitchell & Lemon, 2019

	R1	R2	R3(a)	R3(b)	LM3(a)	LM3(b)	Added £ (a)	Added £ (b)	Suppliers Reporting % local spend (R2)	Suppliers Reporting (sector attributed in R3)	Not median R3 (Unknown contribution)	Suppliers Excluded from R3 spend
2014 – 2015	21,639.60	17,258.10	6,475.31	9,488.53	2.10	2.24	1.10	1.24	17	18		8
2015 – 2016	43,364.23	33,073.86	8,139.59	12,246.76	1.95	2.05	0.95	1.05	21	19		8
2016 – 2017	34,008.43	26,319.69	6,886.68	8,130.24	1.98	2.01	0.98	1.01	18	18		6
Total:	99,012.26	76,651.65	21,501.58	29,865.53	NA	NA	NA	NA				
Average:	33,004.09	25,550.55	7,167.19	9,955.18	2.01	2.10	1.01	1.10				

Notes:

R1 = Initial spend with edible16

R2 = edible16 spend with local suppliers within 20 miles of Market Harborough

R3 (a) = Upstream suppliers reporting percentage of income spent within twenty miles of Market Harborough

R3 (b) = Upstream suppliers to edible16 with known and attributed median percentage spend by sector

LM3 (a & b) = Ratio of initial income to upstream local spend (higher means more money remains in local economic area)

Added £ (a & b) = Additional money to the economic area as a result of spending with edible16

NB:

R1 is ALL income to edible16

R2 is ALL local spend regardless of whether or not the R3 spend is known

R3 has been calculated for known local spend (traditional method) [R3(a)] and has derived values for missing values in sectors where median percentage can be calculated



4. Social Network Analysis (SNA) of the local Food and Drink Map

The second strand of Sustainable Harborough's local food and drink theme involved connecting suppliers with retailers. This was predominantly through the development of two generations of a local food and drink map which was provided free of charge to participating retailers and to the public. The map invited suppliers and retailers not only to list measures that they were taking to promote more sustainable business practices, such as recycling and upcycling, corporate social responsibility, local procurement of services and supplies, etc., but also to identify who they bought their supplies from (in the case of retailers) or who they supplied locally (in the case of suppliers). Using this data set, it was possible to analyse the social network of the local food and drink community, at least indicatively, using the completed application forms of businesses that had been accepted onto version two of the map (n = 40). This aspect of the evaluation, aligns with recent work on network analysis that has been applied to natural resource management (Bodin, Ramirez-Sanchez, et.al. 2011) and to the roll out of domestic energy policies, (Bale, McCullen, et. al, 2013) because it offers a powerful tool for mapping out the complex relations within self-organising delivery systems.

As this aspect of the analysis is retrospective, drawing on data already collected for purposes other than network analysis, it is in common with the LM3 in that there are likely to be significant data missing. Consequently the analysis offered below is provisional and indicative.

The first step in social network analysis (SNA) is to construct a matrix of relations. The type of matrix used to study the local food and drink retail community in Market Harborough was an adjacency matrix of social connectivity; this listed the actors along the top and to the left hand side of the matrix with each (non)connection to a second actor then entered as a 1 or a 0 in the corresponding cell. An SNA is not designed to explore relationships that actors might have with themselves, so all cells that intersect rows and columns for the same actor were recorded with a '0' before loading the matrix into the Open Source SNA package Social Network Visualizer (SocNetV) (Kalamaras, 2014) for visualisation and statistical analysis.

A section of the 54 x 54 adjacency matrix used for this study is given in Table 2 below.

	1	2	3	4	5	6	7	8	9
	Admiral Nelson	Aldins Tearoom	Aldwinkles	Angel Hotel	Ashley Farm Shop	Astley Farm	Bates Butcher	Bell Inn	Bottle Kicking Cider
Admiral Nelson	0	0	0	0	0	0	1	0	0
Aldins Tearoom (NM)	0	0	0	0	0	0	1	0	0
Aldwinkles	0	0	0	0	0	0	1	0	0
Angel Hotel	0	0	0	0	0	0	0	0	0
Ashley Farm Shop	0	0	0	0	0	0	0	0	0
Astley Farm	0	0	0	0	0	0	0	0	0
Bates Butcher	0	0	0	0	0	1	0	0	0
Bell Inn (NM)	0	0	0	0	0	0	1	0	0
Bottle Kicking Cider	0	0	0	1	0	0	0	0	0

Table 2. A section of the adjacency matrix

In Figure 1, below, the corresponding graph generated from the matrix illustrates the connections among actors. The meaning of the directed lines (or arcs) is that one respondent has nominated a second, and the one that was nominated is depicted with the arrow head while the nominator is the origin of the arc. Some of the nodes in the figure are coloured to illustrate this point more clearly. Node 7 (Bates butcher) can be seen as highly connected and an arc leading to node 3 (Aldwinkles) provides an example of how they are connected; nodes 3 and 7 are a dyad with two nodes connected whereby Aldwinkles has nominated Bates as a supplier but there is no supply chain reason for a reciprocal nomination. Similarly, Bates nominate node 6 (yellow), Astley Farm, who are the source of its meat but Astley have no reason to reciprocate by nominating Bates who do not supply Astley.

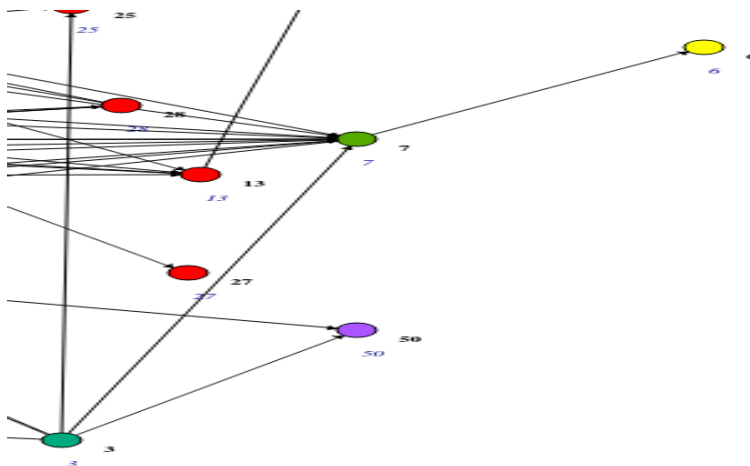


Figure 1: Section of network graph showing nodes (actors) and ties (relations)

There are three network characteristics that underpin the SNA - Network centrality, density and equivalence. Centrality generally represents only the number of immediate contacts a network actor has, but not the direction of the ties (connections) involved (Wasserman & Faust, 1994). To specify directionality, two types of degree centrality are calculated, the first is out-degree, which means the number of nominations (or referrals) made by an actor *to* other actors; the second is in-degree, which is the number that one actor receives *from* others. Network density is a structural measure that reports on the proportion of actors (nodes) in a network which are actually present or linked together.

Because an actor cannot be linked to itself, density is represented as $n(n - 1)$. Finally structural equivalence, or similarity, refers to situations when a number of actors link themselves to a common third party (Burt & Janicik, 1996; Burt, 1984, 1987). This may support assumptions about the homogeneity of the equivalent actors i.e. that they may share similar values, attitudes and behaviours. It may also provide insights that are consistent with Granovetter's (1973) strength of weak ties which highlights both the value of 'looser' networks and the potential vulnerability, lack of resilience, that may emerge from an over-reliance on a close network of strong ties.

A summary of provisional findings relating to the network characteristics is presented in the following table.

Table 3. Summary of network statistics

Statistic:	Value(s):	Implication:
High out-degree centrality	edibLE16 Langton Brewery Aldwinkles	These actors are potentially influential in passing information along to other actors because they link out to other actors in the network.
High in-degree centrality	Langton Brewery Farndon Fields Bates Butcher Waterloo Cottage	These actors are potentially valued in the supply chain, being nominated by other actors, which reflects recognition of their standing relative to the local food network.
Cluster coefficient	Clipstone Egg Langton Brewery Duncan Murray	Only these three nodes converge 'small world' phenomena and suggests limited network redundancy and thereby resilience with relative fragility to stressors, such as removal of key actors.

5. Self-organisation for second-order learning: Becoming a learning project.

The remit for Sustainable Harborough's lessons learned evaluation (LLE), an aspect of human capital, was to identify what had been learned by project stakeholders, team, board members and the funding body from implementing the project (Mitchell, Lemon, & Fletcher, 2019). The LLE adopted a mixed methods approach to eliciting stakeholder¹³ views through an on-line survey and four focus groups and assessing what had been learned from this. Results from this feedback were analysed in two ways, first by 'mining' the responses of participants as texts and secondly by thematic analysis.

To enable text-mining, focus group discussions were transcribed and together with open text survey responses, were examined statistically, looking for word use frequencies and co-occurrences. This statistical treatment of textual data returns an insight into what aspects of the project were at the forefront of participants' minds when discussing it. As such, it is a snapshot in time of how participants expressed themselves in response to questions about the project's successes and areas for improvement. In addition to the statistical treatment of the text, the survey and the focus group responses were analysed for the predominant sentiments, opinions and affective tone of participants' responses yielding a richer texture to the responses than would have ordinarily been possible.

The second LLE approach was qualitative, involving a thematic analysis intended to identify the underlying narrative threads or story-lines that are woven across the focus group responses and

¹³ Here stakeholders refers to members of the business, local government and third sector communities who had engaged with the project during the course of its period of operation.

which assume a coherence around the core ideas and interpretations expressed by participants. Unsurprisingly, there is a saturation effect when the two analytic approaches are considered; what emerged from one begins to become apparent through the second. One would anticipate that this would be the case since the same original staff and stakeholder transcripts are triangulated through the two modes of analysis.

Stakeholders identified that capacity-building (referred to typically by stakeholders as “support”) was a critically important aspect of the work of Sustainable Harborough, and generally rated this as having been successful. In practical terms, capacity-building was expressed as bringing different actors together to work towards common purposes, and given the prominence of this theme and how the strategic approach of the project was explicitly on enabling, this was explored in some detail in the focus group work. However, capacity building was also expressed by stakeholders to be the role that the staff team played in taking responsibility for doing back-office administrative functions, providing reports and offering suggestions about how to progress energy and food activity objectives.

The project has garnered strong positive opinions from the stakeholders who participated in this study. Using the sentiment analysis referred to earlier, the affective loading on parameters such as “trust”, “anticipation”, and “joy” are high, suggesting a positive emotional tone with respect to the discussions about the project. In particular, the parameter of “trust” is almost universally elevated, suggesting that the project has, over its years of operation, secured a solid reputation among its stakeholders and cultivated significant social capital. (Putnam, 2000).

The analysis indicated relatively few references to partner institutions; the parent organisation (the Rural Community Council), is seldom mentioned, neither are the Chamber of Commerce, Seven Locks Housing Association or the District Council. This may reflect how these institutional actors were perceived to play small or low profile roles in the work of the project and its different activities, at least from the perspective of those focus group participants¹⁴. However, when the sentiment analysis, or opinions, of the participants was taken overall, it was evident that the mood was consistent with the online survey response with levels of trust suggesting a high investment in social capital and good will among participants.

While space does not permit a detailed analysis of the focus group discussions, six initial themes were identified and with a series of sub-themes summarised in the following table, were incorporated into evaluation reports which were fed back to the Big Lottery, project workers and the Steering Committee and formed the basis for post project reflection as well as insight for how these actors might engage with similar community projects into the future.

Table 4. Thematic analysis summary with key quotes

Theme	Sub-Theme	Illustrative Quote
	Poor support from political and community leaders	"One of the lessons of Sustainable Harborough is that you won't get the level of engagement and success with the community unless you've got the drive from the top with community leaders".

¹⁴ A series of focus groups were facilitated with 30 stakeholders, partners, and representatives from other involved groups (e.g., Transition Town, Green Open Homes, Waterloo Community Gardens, etc.). Each focus group was attended by one member of the project team to address any specific issues about the project should these be raised.

Theme	Sub-Theme	Illustrative Quote
Milieu	Time-lag in starting new initiatives	"as part of those enterprises, just didn't realise how long it takes to get businesses established."
	Inertia in changing habits	"edibLE16 has been very good for one or two producers ... but I don't think it's got the traction in the community that it should have had"
	Volatility of regulatory and economic contexts	"how difficult it is to sustain things in the face of changing politics, and policy and money around that"
Engagement	Reach of project to Market Harborough communities	" we didn't somehow manage to marshal that (expertise) to help people who really need the help".
	Receptivity to the project	"A lot of the people involved in Sustainable Harborough are likely to be people who already think that way and are already sustainability-minded".
	Synchronicity between offer and local zeitgeist	The project "gave local producers [...] a different kind of community – it wasn't a for-profit cut-throat community, but we're all in this together".
	Communications strategy employed	"It's a question of who the project is targeting in the first place, and not everybody is going to be interested in being involved".
Networking	Project as catalyst	"it takes somebody to make the decisions until someone actually says, I shall look into it for you, it doesn't happen"
	Converging groups around common activities	"a framework, a kind of lattice, to connect or bridge lots of things".
	Enabling stakeholders	"Having a focal group to pull all of those people together and you're not by yourself trying to do everything by yourself"
Governance	Decision-making	"By being upfront about successes and failures, and things that hadn't worked out, which is also a learning exercise for people".
	Steering and strategy	"just don't know what level of success Sustainable Harborough have. I don't know how it's measured. "
	Negotiation of opportunity	"[Sustainable Harborough] has done a good job of finding out where something might be successful and trying to run with it have sometimes had to drop activities if they're not working"
Outcomes	What worked well	"The food is a big success – we've got the Food Map that'll link in with tourism, we've got local restaurants and we've got local food and we know that's being promoted".
	Areas for improvement	"We just didn't take edibLE16 to where it should have been. We were all enthused and had lots of meetings, but then it just tapered off"
	Impacts	"would not have been a community energy organisation here. I cannot conceive of how that might have come about".
Learning	What would be done differently	"if we were to do something like [edibLE16] again, it needs to get more producers involved and get them to commit to it or even to split it, so that you have the marketing bit over here and the main body, the bulk of it, is the producers"
	What was learned	"one of the lessons is that one has to accept that the model you have in the beginning is not the model you end up with, and the lesson is remembering what the reason for doing it was about"

6. Discussion and Conclusion.

In keeping with the 'patchwork' approach to evaluating complex interventions (Connelly & Vanderhoven, 2018), this paper has put forward three complementary perspectives for the evaluation of a community sustainability initiative with the two more-focussed approaches highlighting issues of economic and social capital (local economic benefits and network development). Networks relate to the concepts of *enabling stakeholders* and *converging groups around common activities*; the LM3 approach captures one aspect of the Outcomes theme concerning local economic development. However, the broader thematic analysis highlights several, human capital, issues that the more-focussed approaches did not address. For example, in relation to network development, network analysis does not address in detail the *catalyst* function of a project, that is, how it can shape a particular stance towards the sustainability agenda and as a result, engage with and support different actors to different degrees. In relation to Outcomes, key reported outcomes of the project were the emergence of new platforms (e.g. the Food Map and a new community energy organisation) that can support further activity. The thematic analysis also highlighted several key issues in relation to how a project such as this works – for example the receptivity of the community to an enabling initiative, the support of key individuals and organisations and the influence of the wider national context (e.g. financial support for renewables) on the viability of projects. This wider scope of learning highlights the value of open and iterative exploration of outcomes achieved and influences on this as part of any evaluation initiative.

In terms of the implementation of community sustainability initiatives, the learning from the Sustainable Harborough project points to several key factors:

- the importance of developing *trust and credibility* with key stakeholders (perhaps over several years for a new initiative such as SHP);
- the value of developing and maintaining social networks, featuring both strong – bonding, and weaker – bridging, ties (Granovetter, 1973; Putnam, 2000) to enable interaction around the sustainable development agenda;
- the value of embedded processes for reflection and evaluation so that project stakeholders can use this to inform the project itself and future initiatives.

These points are particularly relevant for a time-limited initiative such as Sustainable Harborough; for example, the networks developed need to be resilient to the withdrawal of a key node (the SHP team) at the end of the project. The learning from the project has to be part of its legacy but should, ideally, be transferable to similar projects and of course to the programme funders and policy makers who may have instigated the process within which it is located. This means that while projects are always unique, with specific contexts, the thematic insights arising from them are more abstract and transferable (e.g. see table 4). It is therefore important for the transfer of such learning that it is not only internalised as legacy but transferable and scalable; something that is key to the effective evaluation and delivery of the Sustainable Development Goals.

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A survey informed propositions for identification, salience and co-option of stakeholders for steering the SDGs in Sub-Saharan African Countries.

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Abstract

Subsets 17.16-17 of the SDGs provide some explicit guideposts for bottom-up implementation approach. However, current strategies show i) lack of adequate localisation of strategies ii) neglect of some impactful actors, and iii) slow and disproportionate progress, especially in the Global South. Addressing these issues inherently starts with understanding the perspective of acting entities. This begs the questions, how do we in the context of Sub-Saharan African countries systematically identify and salient stakeholders and what are their perspectives of the SDGs in relation to appreciation, aspirations and appetite? The study is confined to the implementation of SDG-7 in Nigeria. We use an iterative evolutionary approach that is spherically structured and empirically undertaken several times, continuously updating the insight gained after every phase. A universal tenant is followed that emphasises variety rather than quantity of consultations. The results reveal that while the identity of stakeholders might be similar, their respective influence and impact could significantly diverge across localities. This elucidates the importance of context-specificity in determining 'who and what really account much' to the temporal success of SDGs in Sub-Saharan Africa. Guaranteeing the attributes and entities that when co-opted turn constraints and trade-off into win-win is outside the scope of this study. We conclude with recommendations for entrenchment of sustainable development and further studies.

Keywords: SDGs, Sub-Saharan Africa, Stakeholder Identification

1. Introduction

Sustainable Development Goals (SDGs) are global in nature by virtue of their aspiration for universal application (See section 2 for more on SDGs). But the goals are envisaged to be customised and synchronised with national and local programmes and capabilities (Biermann, Kanie, & Kim, 2017). This is some deviation from prior approaches which were based largely on market-mechanisms or top-down regulation. So from the onset SDGs epitomise inclusive goal-setting and result oriented approach to global governance. Goal 17 highlights some cross-cutting measures to collaborate, domesticate, institutionalise, fund, drive, and follow-up to ensure that the targets are reached. The goal specifically provides some explicit guideposts for bottom-up partnerships and engagement of various stakeholders. The key feature of bottom-up approach is inherent prioritisation of local attributes, such as the availability and the effectiveness of systems, institutions and actors.

However, a systematic review of current strategies shows some common patterns. Among which the key ones that inspired this research are twofold. Firstly, current efforts appear to have been stocked in the circle that typically begins with proposals and access to capital and ends with projects execution. There is hardly any attempt of closing the implementation loops to ensure that lessons gained (in current projects or elsewhere) automatically enter as part of inputs for the next cycle or review. This is due mainly to the common practice of adopting global templates for strategies and identities of actors. Consequently, there is at local levels a lack of adequate consideration for the peculiarities and weights of different actors and systems as well as their respective scalable impacts across bastions and horizons. Specialisation implied here is not to say that a set or individual systems or stakeholders do not deserve consideration. Speciality in our case serves to reinforce a widely held assent that blanket transfer of templates often ignores local circumstances and hardly yields satisfactory outcome. Secondly, if the projects loops are to be effectively closed, the sources and extents of impacts on key indicators have to be systematically traced and integrated.

The basic starting point is to define what really matters and who does it effectively. The former is about the perspectives of stakeholders while the latter is about their identities, both were found to receive casual treatment in practice. Such oversight may be unproblematic to ignore for programmes analyses from aggregate perspective; however, this lapse can be crucial to further progress in collaborative programmes to address disaggregated transition and development issues.

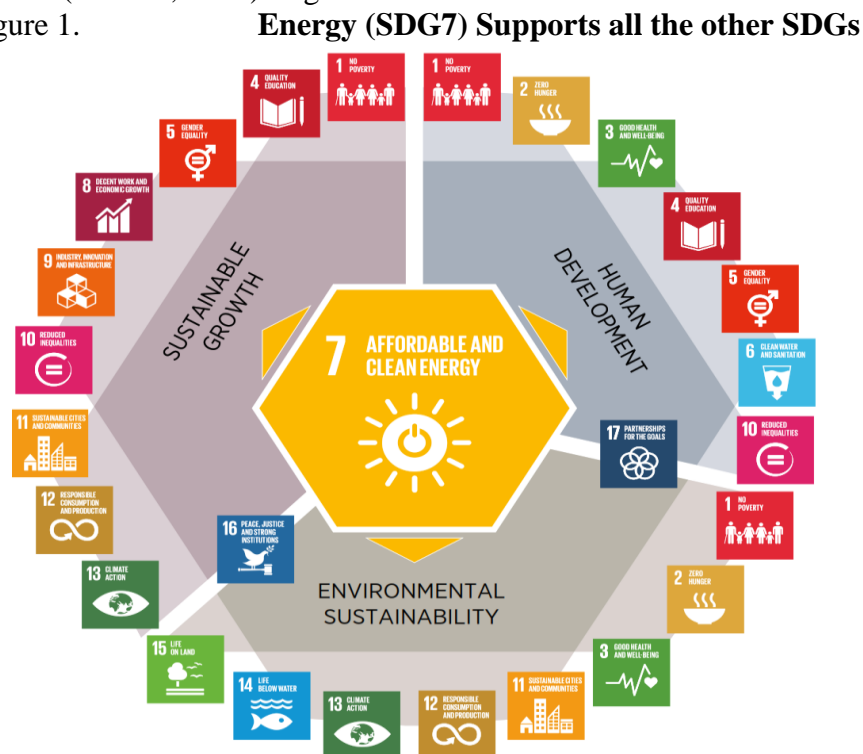
The questions to be addressed where design to demonstrate how to systematically identify and salience stakeholders in Sub-Saharan Africa as well as generate their perspectives of the SDGs in relation to appreciation, aspirations and appetite. Implications of the findings will give insight into the extent to which further reform in governance is needed to accomplish and further entrench sustainable development. In response to this gap, this paper compiles and applies various systems to inform identification and understanding of the perspectives of acting entities as well as ways of engaging them to accelerate SDGs.

To satisfy the task in hand, the article is structured as follows. First, scoping of literature is undertaken to contextualise key concepts and theoretical underpins. It shows that there are a lot of viewpoints out there that could aid coherent contextualisation of the SDGs. Thereafter, cogent methods are compiled for this research. The methods are then combined and illustrated on three projects; to inform identification and salience of acting entities, as well as to establish their perspectives of the SDGs. The final section appraises the strategies used for the case projects.

2. Energy and the sustainable development goals (SDGs)

Lots have been eloquently and clearly written about sustainable development (SD) and the SDGs (UN [United Nations], 2015; UNSC, 2017), and is not to be repeated here. The realisation of crucial causality that clean energy access has on (socio-economic and environmental) development predates the current sustainability drive (Modi et al., 2005). Such synergies were subsequently acknowledged and imbued in the 2030 Agenda through its 17 goals dubbed the SDGs. The International Renewable Energy Agency (IRENA) attempts to demonstrate the central role and crucial interlinkages between SDG7 (energy) and the rest of the goals, along the 3 dimensions of human development, environmental sustainability and sustainable growth (IRENA, 2017). Figure 1 shows that interconnectedness.

Figure 1.



Source: IRENA, 2017

For elaborate list of SDG7 indicators see UNSC, 2017. Over the last decade several projects have sprung up in Sub-Saharan Africa that seek to address one or more of these indicators. The 2019 combined energy progress pamphlet by IEA, IREA, UNSD, WB and WHO offers a dashboard on global progress towards SDG7 by 2030 (IEA, et al, 2019). The dashboard consists of four main elements i.e. electricity for all, universal access to clean cooking fuels and technologies, increased deployment of renewable fuels in global energy mix, and exponential improvements in energy efficiency. The first three provide the handles that informed the grouping of case study projects in this study. Assessing energy efficiency adds no value to our objectives, is therefore dropped. Projects/interventions presented here are necessarily compressed and are the minimum selected to cover the objective of this study based on the adapted indicators:

- promote universal access to modern, affordable and reliable energy services
- towards increased access to electricity, clean fuels and technology
- flows of (local and international) financial aids in support of clean, renewable and hybrid energy and energy systems research, development and production
- communal/mini level projects and interventions
- operational (completed or phase-in)

It is common for a single interventions initiative to encapsulate projects that focus on two or more of the adopted handles. In such cases, individual components are to be treated based on our categorisation scheme. Thus, the clusters are not necessarily mutually exclusive. As also to be seen, although the case study projects/interventions fall under SDG7, by design or impact they cut across several other SDGs.

2.1 (Host) Community electrification initiatives

Several large-scale corporations imbed sustainability initiatives in their operations and plans as part of their corporate social responsibilities. Virtually all International Oil companies (IOCs) and their local counterparts have one form of sustainability project/intervention or the other. The ones to be mentioned here does not in any way signify either approval or rating. Eni E&P (exploration and production) is one of the IOCs with extensive oil and gas interests in Nigeria. The company has through its subsidiary, Nigeria Agip Oil Company (NAOC), embarked on intervention projects for local communities to improve access to affordable and sustainable energy (Eni E&P, 2019). Some of these projects include electrification of local communities through direct connection to sites of operational, and installation of off-grid system to supply electricity to communities. Around 38MW is made available from operational sites to serve about 300,000 in 36 beneficiary communities. The 15MW off-grid system serves about 160,000 people in 44 beneficiary communities. Both systems are gas fired and located in the Niger Delta region. Energising Economies Initiative (EEI) include electrification of 1047 shops at Sura ultra-modern shopping complex in Lagos State through gas fired Independent Power Project (IPP) electrification project. Similar project is implemented at Ariaria Industrial Market in Abia State where the first phase of the project has powered 4000 shops.

2.2 Clean fuels and technologies

Access to clean cooking fuels and technologies remains a major issue in West Africa. Regional access has increased at about 0.3% annually between 2010 and 2017, but the progress is dwarfed by increase population in the corresponding period which has expanded by about 2.5% (from 750 million to 900 million). This widens the access-deficit population by around 150 million in the region. Lots of these people live in Nigeria, where only 7% of the country's almost 200 million population have access to clean cooking energy. Some of the key efforts to arrest the situation in Nigeria have been around promoting Liquefied Petroleum Gas (LPG) and clean cookstoves. Several projects have been implemented under the National Clean Cooking Scheme (NCCS) which is steered by a Unit of Federal Ministry of Environment (Renewable Energy Programme). Specific projects include secondary schools kitchen LPG-retrofit arrangements through collaboration between the UNDP and Renewable Energy Programme (REP). Kitchens of four schools have been retrofitted with LPG stoves with a view to reduce and eventually eliminate more environmentally detrimental fuels such as Dual Purpose Kerosene (DPK) and solid biomass. Another collaborative project under the NCCS is between the REP and the Clean Cookstoves intervention of the National Assembly. The initiative has successfully provided communities with clean cookstoves across Akwa Ibom and Kwara States.

2.3 Renewable energy development

Bisanti Community solar mini-grid project in Niger State was among the model community-scale solar electrification projects in Nigeria. The Bisanti project was donor driven and has a peak capacity of 37.8 (kwp) and serves 200 households (Offgrid, 2017). Under the Rural Energy Access Project (REAP) an intervention at Mutum Bui, Gassol LGA, Taraba State electrifies 600 household through installation of stand-alone solar systems and training of locals. Renewable component of Energising Economies Initiative include electrification of 13,600 shops at Sabon Gari market in Kaduna State through decentralised solar systems.

Dedicated off-grid solar system is installed under the Kigbe Mini-grid Project to uninterruptedly power 5 businesses and 145 households in Kigbe village, a suburb of the Federal Capital Territory, Abuja. The project was implemented with financial and technical support from five development support groups (Havenhill, 2017). The only fully operational 1MW capacity solar hybrid power plants are the Bayero University, Kano and the Usama Dam, Abuja projects. Both were funded through international development assistance. It is worth mention here that the Federal government has commenced the Energising Education Programme (EEP) to supply Federal Universities with sustainable and clean power. First phase of the project has combined capacity of 28.5MW using solar hybrid plants. So far, 2 out of 10 sites have been completed and the rest are at different stages of completion.

3. Stakeholders and Saliency

There are plethora of definitions for both Stakeholders and Saliency. Here we focus on adaptations made for this study. Freeman (2010) defines a stakeholder as any specific or set of entities that is capable of either affecting or being affected by the achievement of an objective, programme or project. It is widely held that the support of stakeholders is crucial in creating and sustaining winning coalition, which is necessary for the long-term viability of virtually any projects, programmes, plans and policies (Bryson, 2004). Saliency is the quality and the degree of deserving priority among competing claimants. Ronald, Bradley & Donna (1997) identify three key attributes for stakeholder classification and saliency based on normative assumption of the entities that should be given attention i.e. power of influence, legitimacy of affiliation and urgency of claim. Both the authors and critics alike recognise that these attributes are variable, subjective and non-exhaustive. Thus, while the stakeholder status can be stable, it is possible to gain or lose saliency across the span or stage of involvement (Singh, 2019a).

4. Theoretical Foundation

Attempt is made to justify the urge to complement (hard, soft and critical systems) methodologies due to the shortfall of each to oblige fully to the three (technical, practical and emancipatory) human cognitive spheres (Flood and Jackson, 1991). Pluralism presents a neutral position which promotes the simultaneous deployment of theories and techniques at different stages of an intervention (Jackson, 1997). In these lights, sustainable development agenda fits well in the criteria of evolutionary perspective. The key elements of evolutionary standpoints are complex systems, boundary judgement and problem (re)structuration. Here a brief review of these elements is presented to help make sense of the complexity of communal and medium-large scale SD projects, before delving into methods to help answer current questions. But before then, we briefly discuss the concepts of stakeholder and saliency.

4.1. Sustainable development programmes/projects from the perspective of complex systems

Complex system is premised on rejection of the validity of analytical strategies in which schemes are reducible to the sum of their parts. Causation in real world is complex. In order words, causality may not necessarily be equal and opposite, small changes somewhere or in specific aspect may result in dramatic outcome elsewhere or from the whole. Multiple causes may combine to produce a single outcome (and vice versa) in ways that are non-additive. This is among the reality of schemes whose crucial dimensions evolve temporally. Another key element of such systems and societal problem situations is that outcomes and features

emerge as a function of continuous (inter and intra) interactions between components, outcomes and feedbacks as the system/situation evolves.

4.2. Determining the boundary

Ulrich (1987) opines that the emphases on boundary judgement (context/scope of application) in applied and basic sciences bother on clarifying what/who are involved and affected. He observes the common and inadequate approach of basing boundary judgements on data availability and technical hindrances. To him the key to understanding any system/project lies in understanding its environment; and that scientific rationality of any boundary depends less on priori boundaries than on those eventually informed by the purpose of such systems/projects. Drawing boundaries is a normative issue in complex system approach. It is particularly important not only as regards to identification of systems/projects scopes but acting entities as well. What and who are involved or otherwise is relative to defined boundary: a change in scope may prompt a different problem analysis and, likewise, a different solutions, changes and outcomes. Boundaries are explored and justified via debate between those affected by and involve in the design (Achterkamp & Vos, 2007). Even the most comprehensive system standpoint cannot sufficiently validate its own normative implications without such consideration (Ulrich, 1987).

4.3. Problem (re)structuring

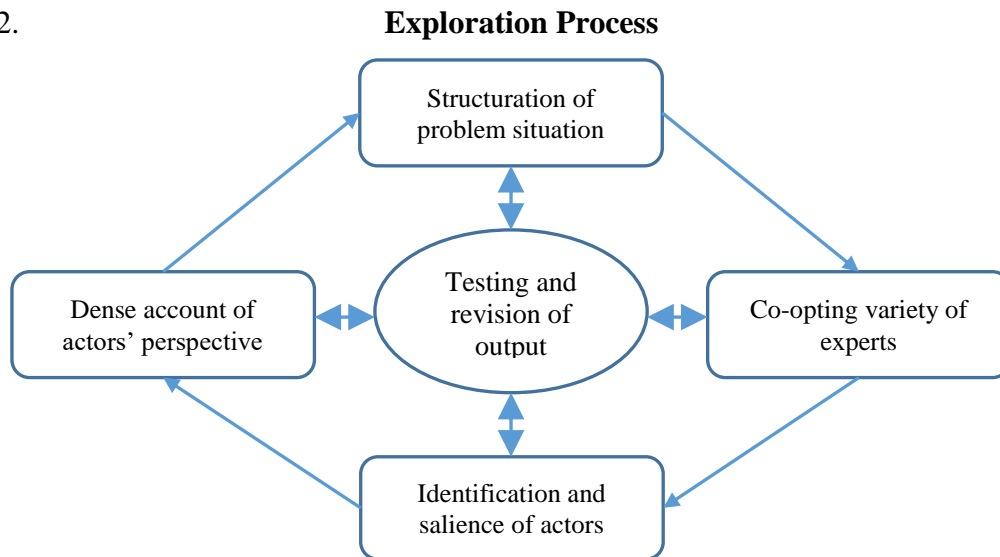
PSMs structure (decision) situations, problems and issues instead of solve them. In essence, problem structuring approaches offer methods for representing a problem situation in a way that enable acting entities to clarify a common quagmire, agree on possible actionable issue or problem within it, and ultimately converge on commitment to address or ease it (Müller, Groesser, & Ulli-Beer, 2012). The pillars of typical PSMs-based analyses are system-view, qualitative and value-centrism (validity, reliability and transferability). Alberto Franco (2009) observes that application of PSMs has gained ground in multi-organisation setting which more often than not characterises the typical societal problem situations. Among prominent PSM approaches of are Soft System Methodology (Checkland, 1981), Strategic Choice Approach (Friend and Hickling, 2005), Strategic Option Development and Analysis (Eden and Ackermann, 1998), Journey/Analysis Making, Drama Theory (Bennett, Bryant, & Howard, 2001) and Robustness Analysis (Rosenhead, 2001).

Sustainable development presents a multifaceted problem situation that is characterised by multitude of perspectives and actors, conflictingly diverse and/or incommensurable interests, fundamental uncertainties and key intangibles. These features fits the criteria and are well suited for analyses using problem structuring methods (PSMs) (Mingers & Rosenhead, 2004).

5. Description of the Methodology

In order to achieve the target aim a bespoke methodological combination is made of theoretic complex systems (Bar-Yam, 2004; Bar-Yam, 2011; Byrne, 2013) and stakeholder identification and saliencing (Ronald et al., 1997; Singh, 2019), iterative assembly framework (Müller et al., 2012) and Delphi technique (Avella, 2016; Jacqueline & Bobeva, 2005). The latter serves also to intersubjectively validate the outcome of the research. This study is not lengthy enough to discuss these methods, but elaborations can be followed through the highlighted references. Our exploratory approach is evolutionary and empirically iterated to densely collect accounts on the issues of interest, as schematically presented in Figure 2.

Figure 2.



Source: Based on Müller et al., 2012 and Loorbach, 2010.

First, we contextualise the problem situation. Section 1 narrows down to the issues and questions covered in this study. Consultations are restricted to only experts (from both public and private sector), for two reasons. Besides from their reach knowledge, experts are found to be capable of representing the standpoints of other actors in the system (Müller et al., 2012). We follow a widely accepted research practice which favours variety rather than quantity of consultations. Drawing expert from a diverse background also serves to stem any likelihood of circumstantial bias (Anyan, 2013). Access and getting expert committed is a common challenge in research (Harvey, 2011; Hochschild, 2009), including this one. The norm is to do with what is secured within prevailing constraints (time and other resources), as long as the number engaged is sufficient to achieve saturation in either or both understanding and data. Then, a scoping is undertaken to identify and categorise actors that have stake in the successful delivery of the SDG projects, focusing on projects highlighted in section 2. In addition to providing initial boundary, emphasis on the underscored projects ensures context-specificity to eventual outcome of the study. Scoping provides preliminary input for enrichment and saliencing by the respondents. The final stage involves the exploration of stakeholders' perspectives of the SDGs. Delphi technique was used to steer the two activities with respondents.

5.1 Steering the Delphi toolkit

Delphi technique is a questionnaire-based and structured panel engagement method used to solicit the opinion of experts on a given complex or novel issue. It can be face-to-face or remote and is widely received. See for detailed description, pros, cons and areas of application Avella (2016), Imran (2007), Jacqueline & Bobeva (2005) and Thangaratinam & Redman (2005); and for comparative and nuanced synthesis with other methods see Mukherjee et al. (2018). Delphi survey is adopted for its potency in collecting current data and exploring priority of social goals. Effort was made to mitigate its pitfalls. Table 1 summarises the Delphi design.

Table 1.

Architecture of Delphi Inquiry

Criteria	Identification, saliencing and insight
Purpose of the study	Exploratory and ranking
Number of rounds	3 rounds
Participants	Heterogeneous
Mode of engagement	One-to-one and e-access
Anonymity	Full
Media	Pen-and-paper, email, phone calls and WhatsApp
Concurrency of rounds	Sequential

Source:

The survey followed the 3 conventional phases of exploration, distillation and utilisation. Exploration (Linstone & Turoff, 2002) stage entailed structuring the problem, scoping literature, designing the survey and instruments, and assembling the panel (sections 1 and 2). Distillation (Ziglio, 1996) this involved the condensation of information through the 3 questionnaire rounds. Utilisation (Jacqueline & Bobeva, 2005) stage typically has operational undertone. Here utilisation is limited to analysis, discussion and implication (section 4).

Figure 3.

The Delphi Process

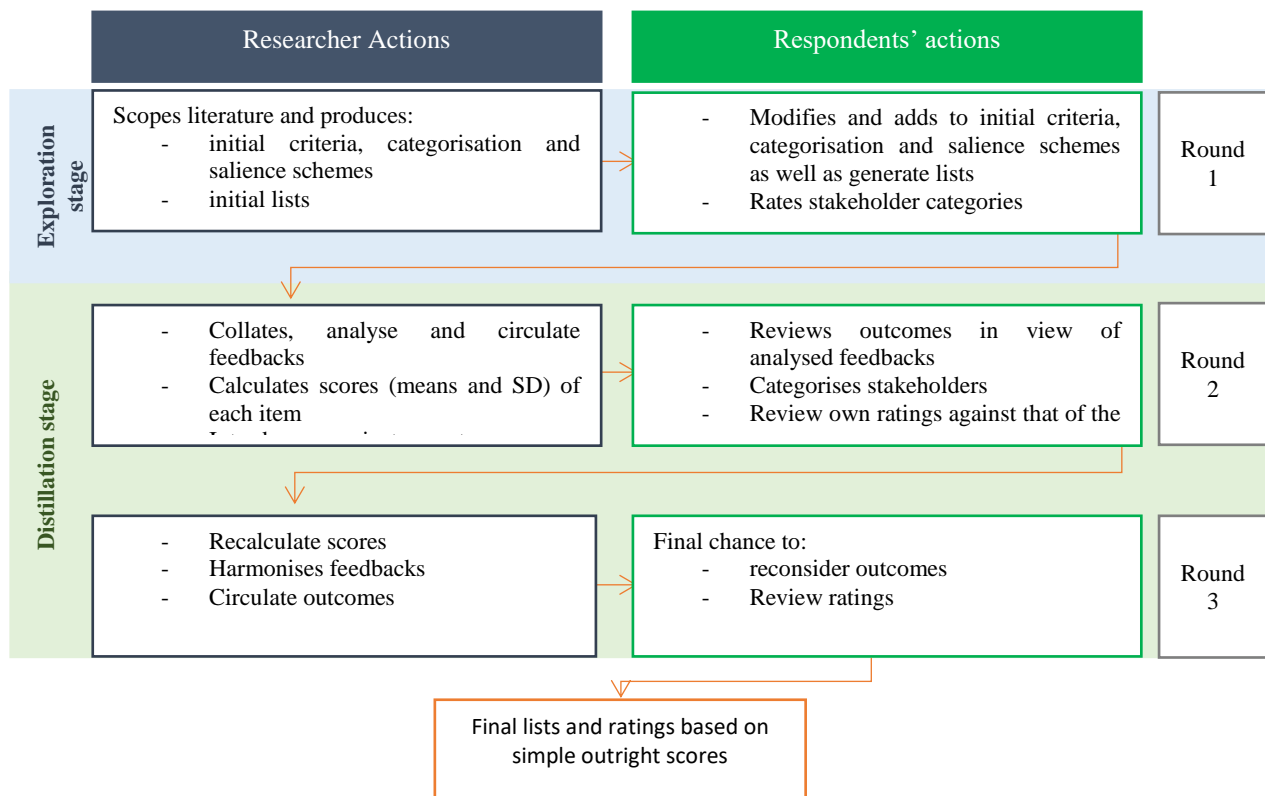


Table 2. **Panellists Selection and Rate of Survey Completion**

Selection process	Expertise of Panellist			
	Public sector	Business and industry	Non-gov'tal organisation (NGO)	Academia
Identified/recommended	16	5	7	21
Invited to panel	6	5	6	6
Agreed to join	4	3	6	5
Participated in at least on round	3	3	4	2

Source: Research Design

A total 49 experts were identified, some of which was by recommendation. Invitation was extended to 23; 18 accepted to partake in the Delphi. However, only 12 participated in at least 1 round of questionnaire. Every session involved at least 2 respondents each from public sector, business and industry, and non-governmental organisations (NGOs), and the academia. The variation is due to some opting out and fresh ones invited to fill the vacuum. Participants from the academia were well vast in the field sustainable development and the SDGs, as expected. Those from the public sector were top-level official in charge of implementation, regulation and oversight. Respondents from business and industry were senior managers in firms with experience as vendors in implementation of SDG projects. Representations from the NGOs have had a long history in socio-environmental activism.

5.1.2 Description of survey instruments

Participants Information Sheets and Consent Forms were circulated to informants to explain the purpose and the scope of the research. Voluntary participation, including freedom to withdraw at any stage as well as anonymity of panellists were adequately explained to respondents. Adequate explanation was also provided regarding the Delphi process was sufficiently described. More details on the instruments are integrated in the following section.

6. Analysis and discussion

The outcome of the Delphi is presented and discussed in the proceeding subsections. This is done on item-by-item basis to unmask important findings. Each result is instantaneously interpreted before the subsequent ones are introduced. A subsection is dedicated per key inquiries of the survey. These include criteria and identification of stakeholders, stakeholder categorisation, stakeholder saliencing, stakeholder perspectives, and persistent challenges in the pursuit of SDGs. The section concludes with some constraint of the study. Lists are as much as possible harmonised to enhance clarity of presentation.

6.1` Criteria and Identification of Stakeholders

Available normative criteria for identification of stakeholders is still inadequate (Bryson, 2004). The convention is to simply ask who are the stakeholders and resultant list adopted. In trying to ensure rigor in the process, there is the need to develop a well thought principles that could inform generating an elaborate list of stakeholders.

Among the novelties of this study is the introduction of expanded cyclical process of identification of stakeholders that starts with the identification of inherent activities/stages of a phenomenon. The approach is essential to fully account for the dynamic status of stakeholders across the lifespan of a project/intervention. The first question was to identify the typical activities/stages embroiled in the lifespan of the selected case studies. After collation and review, the panellists settled for the following activities:

- Standards and regulation
- Advocacy and activism
- Project/intervention stage
 - Conception
 - funding
 - Planning
 - Implementation
 - Monitoring and evaluation
- Maintenance
- Refurbishment
- Decommissioning/upgrade
- Patronage/clienteles
- Victims and displacement
- Contacts/Entry points

Individual projects or interventions may not embroil every activity, but it is resolved that all the selected projects and interventions are holistically represented.

Streamlined List of SDG7 stakeholders

- | | |
|---------------------------------------|--|
| i. Affiliated NGOs/activist | xi. Investors |
| ii. Apprentice (persons/institutions) | xii. Larger society |
| iii. Clienteles | xiii. Linkage sectors/industries |
| iv. Community associations/societies | xiv. Non-affiliated NGOs/activists |
| v. Donor institutions | xv. Other support groups |
| vi. Funding guarantor | xvi. Service providers |
| vii. Faith-based institutions | xvii. Targeted persons/groups |
| viii. Governments | xviii. Traditional institutions |
| ix. Host communities | xix. Trade union/associations |
| x. International pressure groups | xx. Victims/displaced (persons/entities) |

The next question was to as many as list under each stage all the stakeholders (people and institutions) whose inputs were needed to deliver the instrumental ends of these SDG7 projects/interventions. Below is the condensed list of stakeholders after using negation principle to select only one out of entries that play same or largely similar role. Some panellists felt that excessive condensation of the list could lead to omission of some stakeholders. Specific example is that 14 governmental bodies at different tiers appeared on





the initial list but were eventually lumped together and labelled as ‘governments’. But it was aggregately agreed that the final list was representative of virtually all the identified stakeholders. This sets the tune for the next task – to categorise stakeholders based on their relationship with the SDG intervention.

6.2 Categorisation and salience of stakeholders

Several categorisation schemes have been devised along the original works of Ackermann & Eden (1998) titled ‘Making Strategy: The Journey of Strategic Management’ to aid description of the respective roles of stakeholders. Most techniques typically use either Venn or matrix designs to assess and place stakeholders based their corresponding degree of power and/or interest (Reed et al., 2009). Adaptation made here follows Ackermann & Eden, 2011; Reed et al., 2009; Pichler, 2019.

Panellists place each of the stakeholders identified in the preceding subsection where in their respective views best describes their status on a two-by-two affected-affecting grid. There was initial apprehension over the difficulty of arriving at mutually exclusive clusters. However, it was unanimously acknowledged that membership of any particular group can be gained or lost just as the status of a stakeholder itself. The panellist also agreed to the possibility of a single stakeholder to qualify for more than one group. Below is the final outcome. Grieve

Table 3. **SDG7 Interest and Influence Grid**

 Affected 	Subjects 1. Clienteles 2. Targeted persons/groups 3. Victims/displaced (persons/groups) 4. Service providers 5. Linkage sectors/industries	Benefactors 1. Governments 2. Donor institutions 3. Investors 4. Funding guarantor 5. International pressure groups 6. Other support groups
	Observers 1. Host communities 2. Larger society 3. Non-affiliated NGOs/activists 4. Apprentice (persons/institutions)	Referees 1. Traditional institutions 2. Faith-based institutions 3. Community associations/societies 4. Trade union/associations 5. Affiliated NGOs/activist
	 Affecting 	

The panellists resolved that host communities, larger society, non-affiliated NGOs/activists, and apprentice (persons/institutions) fall under the Observers. To them, these are category of stakeholders that have little influence on the project decisions and are hardly affected by its outcome. General disposition towards Observers is that it suffices to keep them abreast of progress, without being directly involved in any activities. Projects' websites, wikis and newsletters and media are among the commonly used channels to update observers and disseminate information about important developments.

Panellists decided that Traditional and Faith-based Institutions, Community Associations/societies, Trade Union/associations, and Affiliated NGOs/activists pit under Referee class in their relationship with the project. They consider this group as a kind of context setters. Panellists agreed that these Referees were highly powerful in terms of their capacity to influence the context of the project but have low interest in its outcome. They believed that without the support of Referees the success of the project may be at risk. The panellists resolved that concerted effort has to be made to ensure that ideas, concerns and opinions of Referees are heard and as much as possible accommodated. Generally, where the standpoints of Referees were not (technically or economically) feasible, ways had be found to persuade them with a view to retain their buy-in. Failure to do these often lead to nasty surprises. Referees were often intimidating and pushy whenever they decided to participate.

Panellists resolved that clientele, targeted persons/groups, victims/displaced (persons/groups), service providers and linkage sectors/industries were all Subjects in their relationship with the project. They believed that these were the marginal entities that directly or indirectly the development interventions were set to empower and were widely considered as supportive. They were the targeted end-user group, beneficiaries or victims of any anticipated behavioural change. Subjects generally have high stake but often lack influence to affect the course of decisions, although they may become powerful by forging alliance with other groups. Subjects should be involved at every level, inviting and accommodating all their feasible feedbacks.

Panellists resolved that Governments, Donor Institutions, Investors, Funding Guarantor, International Pressure Groups and Other support groups qualified as Benefactors. The panellists felt that these Benefactors are the key players that directly or indirectly provided some critical (capital or know-how) resources on which the success of a project or intervention was leveraged. They believed that both the interest and influence of these players were high. To them, these Benefactor typically had to be actively groomed in order to avoid hand-offs.

6.2.1 Comparative Saliency of Stakeholders

Previous sections have shown that identifying the stakeholders is one thing, and knowing how to and effectively engaging them is entirely a different thing. It is widely acknowledged that Success in the former doesn't necessarily trickle to the latter. This subsection compares the result of stakeholder saliency with what obtains across different spheres. It was clear from the onset that the comparison was not to relegate any relationship but to stimulate purposeful engagements of stakeholders. This removes trade-off from the table ab initio.

The panellists first assessed the business as usual (BAU), before assessing the impactful relationship in propelling the SDGs. There was unanimous convergence that prevailing emphasis has been on benefactors, subjects, referees and observers – in that order (see Table 4). On the other hand, the panellists were of the view that for developmental programmes like the SDGs to have a realistic chance emphasis has to be on referees, subjects, benefactors and observers, respectively (see Table 5).

Table 4			Table 5		
BAU			Impact-based		
Stakeholder	Mean	S.D.	Stakeholder	Mean	S.D.
Benefactors	1.25	0.43	Referees	1.75	0.83
Subjects	2	0.71	Subjects	2	0.71
Referees	2.75	0.43	Benefactors	2.25	0.83
Observers	4	0	Observers	4	0

The mean values show the respective ranks, while standard deviation show the degree of consensus. It could be seen that agreement was higher for the BAU case. However, with over 80% in agreement, it was straightforward and there wasn't the need to carry the dialogue to the next round.

Table 6 Comparative Salience of Stakeholders

Stakeholder/rank	1	2	3	4
Firms ¹	subjects	employees	benefactors	observers
Power vs interest ²	benefactors	subject	referees	observers
Result1 (BAU)	benefactors	subject	referees	observers
Result2 (impact-based)	referees	subjects	benefactors	observers

¹ Corporate Finance Institute (n.d.); ² Pichler, 2019 and Reed et al., 2009

Table 6 summarises the contrasts. Most commercial firms are conventionally subject-centric. Design and development of products and services are built around the customer, before the interests of employees (referees), investors (benefactors) and then observers are taken into account (Corporate Finance Institute, n.d.). Some popular analytical schemes (see section 3 for more details on analytical schemes and their theoretical leanings) agree that benefactors are paramount, before subjects, in that order. This approach has been successful in many areas but has been inadequate in driving the SDGs. Impact-based salience is to address such inadequacies in stakeholders engagement with a view to enhance delivery of the SDGs in SSA.

6.3 Perspectives of Stakeholders

Here the focus is restricted to three components i.e. appreciations, aspirations and appetite. These issues were introduced for the panellists to comment. The outcome of that dialogue is presented in the following subsections.

6.3.1 Appreciation

Appreciation can be any acknowledged benefit credited to a course. For this study, appreciation relates to those recognisable and valuable benefits gained because of the SDG7 interventions. The panellists were asked to list the ways that in their respective view the interventions benefit or stand to benefit the stakeholders. Panellists saw opportunities for or access to at least one or more of the following as the aspirations:

- Entrepreneurship and commerce
- Direct jobs and income
- Vocational skills and training
- Lighting (for education and security)
- Improved health and services
- Social amenities e.g. access road, street lights etc.
- Increased attention to other local problems
- Public engagement, accountability and feedback
- Windfall (cash or in kind)
- Improved ecosystem
- Attitudinal change

6.3.2 Aspiration

Aspiration relates to those outstanding strong desires arising from their access that stakeholders still want to accomplish. The question was to list all emerging aspirations that have arisen following the SDG interventions. The panellists generated the following:

- Upgrades and capacity expansion
- Awareness and maximisation
- Support and empowerment
- High-level involvement and participation
- Ownership and control
- Champions and models
- Public goods (free-rider orientation)
- Bandwagon and snob effects

6.3.3 Appetite

Appetite relates to the urge for more activities by stakeholders arising from access or awareness. The panellists were asked to list all observed in the stakeholders' appetite for SDGs.

- Willingness to commit to and adapt sustainable practice
- Proliferation of service and linkage enterprises
- Growing enthusiasm about SD
- Individuals and communities taking initiatives

7. Implications for the SDGs

The need for more emphasis on customised (localised) SDG approaches has more than ever become apparent. Regardless of the target to the SDGs, the stakeholder is the primary liaison and a sort of clincher of the acceptability or otherwise of eventual outcomes. Getting the stakeholder engagement right could be antidote to many pitfalls. Disaggregating the stakeholder identification process down to project/intervention components and phases/stages adds rigor to the entire implementation process. Such practical adjustment could increase focus on bottom-up considerations, which are prerequisite for entrenching sustainability inclined changes, especially in energy sourcing, use and behaviour.

It is widely held that the status of a stakeholder can be gained and lost and also the urgency of their relationship might change across the lifespan of a project/intervention. The need for functionally differentiating how and when stakeholders are involved is emphasised. This to a large extent allows for capturing the dynamics of both the status and the relationships of stakeholders with the It is widely held that the status of a stakeholder can be gained and lost and also the urgency of their relationship might change across the lifespan of a project/intervention.

Another important implication of findings of this study relates with the design and dissemination of educational programmes geared towards entrenching sustainable development. A lot has been done at the level of structure learning institutions as well as national and higher levels through the Education for sustainable development (ESD) platform of the United Nations. There is also plethora of governmental and other bodies advocating for sustainable development. However, subsection 6.3 shows that stakeholders' perspectives of sustainable development remain significant diverged. This explains there are still lots of misconceptions about sustainable development project/intervention, such as the public goods

and financial windfall expectations. The content and intensity of ESD and other advocacy drives needs to be tailored and varied towards grass-root levels reorientation of both end-uses and end-users as well as manage expectations.

7. Conclusion

Sustainable development problems are complex and often not pliable to linear analysis. Although stakeholders have been recognised as the fulcrum of bottom-up approach to sustainable development, effective ways of appropriately engaging them are still lacking. Formal suggestions have been demonstrated for capturing the traits, values, central interests, and actions best carried out by individual or category of actors identified as stakeholders that in one way or another drive the SDGs. The results elucidate the importance of context-specificity to the practice and literature on ‘who and what really account much’ to the temporal success of SDGs in Sub-Saharan Africa. We also show that identity, diversity and engagement of stakeholders is not a one-size-fits-all scheme, and that addressing such a fault in approach and adequately co-opting various stakeholders and their perspective could be the key for timely hitting the SDG targets in ways that are feasible technically and palatable socio-politically. To achieve that, stakeholder engagements have to be functionally differentiated across localities to benefit local attributes.

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Session 8

Business solutions to address the SDGs

Women centred empowerment: developing solutions to improve living conditions in rural Mexico

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ABSTRACT

In the community of Jaltepec, San Jose del Rincon region in the State of Mexico, poor cooking practices and lack of access to clean water have led to dangerous levels of in-house air pollution and health deterioration. In addition to these adverse health problems, the lack of energy and clean water force mainly women and children in rural communities to spend a significant amount of their time collecting firewood and water. These women are often victims of domestic violence and are constrained from accessing decent wage employment, educational opportunities and livelihood enhancing options. The aim of this work was to propose and develop simple and sustainable solutions for the problems faced by the Jaltepecan community in rural Mexico using a designer approach. A design framework was developed by merging a number of design methods aiming at delivering more human-centred approach. This design framework was used in conjunction with supporting approaches of social sustainability and gendered innovation. To address the community's problems surrounding access to clean water, indoor air pollution and time wasted collecting resources, three technologies were developed into functioning prototypes. All the prototypes were designed to be manufactured locally, with basic materials and tools.

Keywords: Design Thinking; Social Sustainability; Gendered Innovation; Rural Community.

INTRODUCTION

Jaltepec is a rural community in the municipality of San José del Rincón located in the Western part of the State of Mexico (Figure 1). It is home to approximately 1400 inhabitants (SEDESOL, 2013), most of which are from the indigenous group of the Mazahua community, the largest indigenous group in Mexico (Whaites, 2015). Almost 50 % of the total population of this municipality is considered to be living in extreme poverty (Coneval, 2015) with lack of access to electricity, clean water and basic infrastructure such as drainage and sewerage systems (Dirección de Análisis Territorial, 2005; CONAPO, 2013).

The temperature in this area ranges between 10 and 14 °C (INEGI, 2009) thus the households require heating all year round. The most common form of cooking and heating is with

firewood, collected from surrounding forests. Wood burning without proper extraction and ventilation, can produce extreme indoor air pollution and result in respiratory diseases (WHO,2006). The community does not have access to a piped water distribution system (Dirección de análisis territorial, 2005), some individuals harvest rainwater but the majority of the population uses water collected from nearby rivers and streams (Zarza *et al.*, 2017). Locals walk for an average of one hour a day to collect firewood and water, this is a considerable physical task, especially because it is typically carried out by women and children (Zarza *et al.*, 2017).

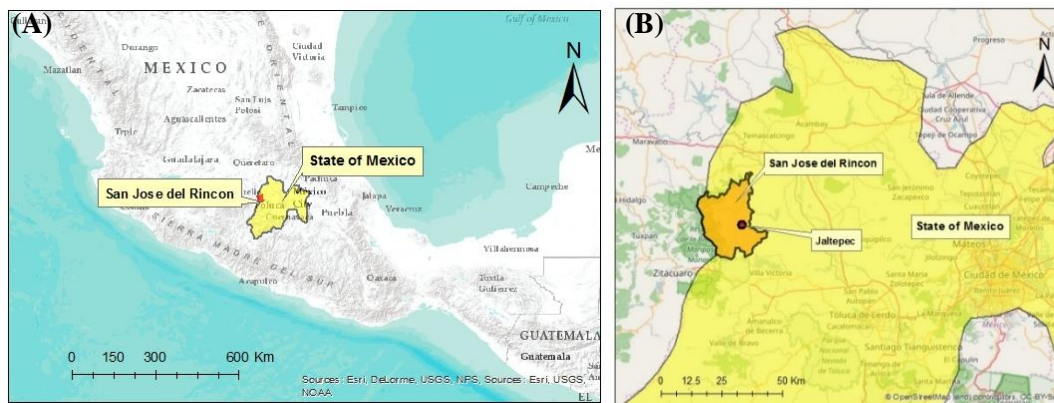


Figure 1. (A) Location of San José del Rincón and (B) Jaltepec.

The International Fund for Agricultural Development (IFAD) (IFAD, 2004), identified that women suffer the most within indigenous communities, due to their limited access to key resources including such as education, land and money. It can be argued that the role of women especially in the rural community like Jaltepec extends further than just the role of ‘home maker’. However, despite this, rural women play an almost non-existent role in decision making processes when it comes to technology uptake (IFAD, 2004). In addition, it has been recognised worldwide that the construct of research and innovation in society lacks focus on women. The Research Council of Norway (2014) expressed that this lack of focus or ‘gender bias’ is harmful to society. It is for this reason that this project takes on aspects of ‘Gendered Innovations’ which is the method of analysing gender and sex during the research process to produce new, relevant information and technologies (Schiebinger, 2014). Gendered innovations create opportunities for discovery, save time and money and encourage gender equality. The importance of women in the Jaltepec community and the struggles that they face requires a woman centred empowerment approach. This paper describes the second phase of a project aimed at improving the living conditions of women in rural Mexico (Zarza *et al.*, 2017), by developing simple and sustainable solutions for energy and water supply at local level. ‘Design Thinking’ was employed for this project to ensure a more user focused approach.

METHODOLOGY

Design Framework definition

A project framework was developed, employing design methods to aid the design thinking double diamond approach. Methods were compiled from two sources, both tailored towards

solving complex development issues; the Human Centred Design Kit (IDEO, 2015) and the DIY Toolkit (Nesta, 2014). The selected methods (1-7) are outlined in Figure 2A.

Application of the design methodology

Understanding and definition of the problems

1. Summarise Learnings

The first stage of the process involved detailed analysis of an ethnographic study carried out on the Jaltepec community by Zarza *et al.*, 2017. Analysis of this study was supported with tertiary research to gain a deeper understanding of cultural, political, social and environmental factors affecting this indigenous group, with a focus on women in the community.

2. SWOT (Strength Weakness Opportunity and Threats) analysis

A SWOT analysis for the community was used to understand internal and external barriers for the community, as well potential levers for positive impact. A summary of the most prominent results are shown in Figure 2B.

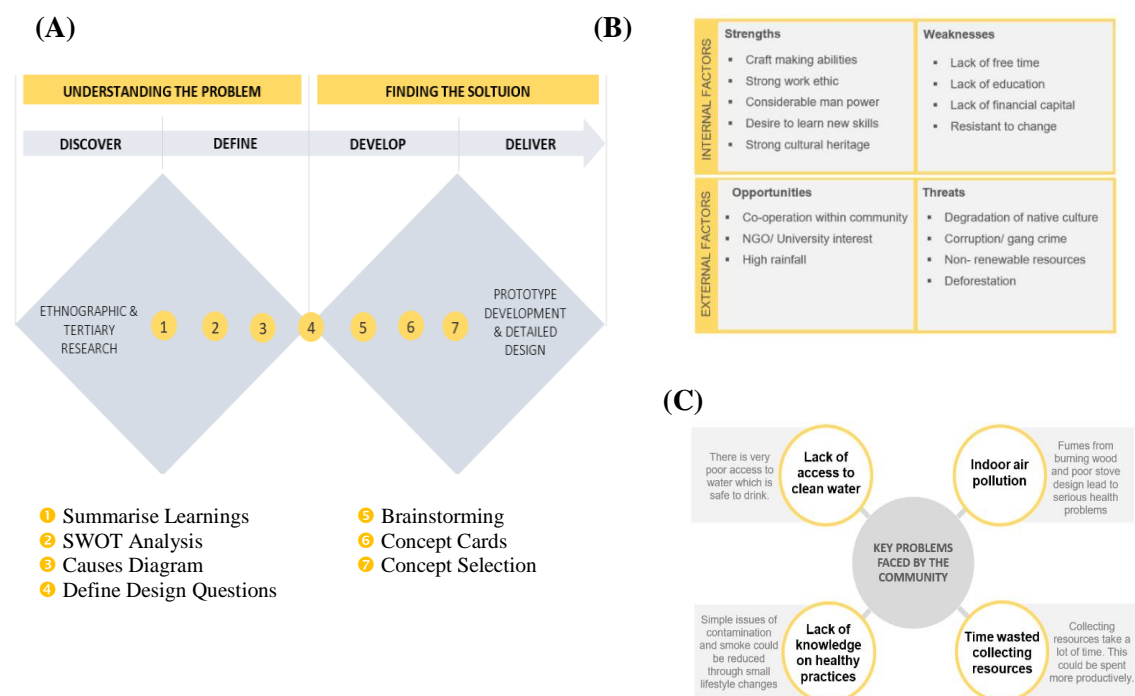


Figure 2. (A) Design framework used for developing the solution to the energy/water problem in Jaltepec, (B) summary of the SWOT analysis and (C) Causes Diagram Summary of key problems faced by the community.

3. Causes Diagram

As is common with many rural development cases (Scoones, 2009), analysis of the ethnographic results highlighted how there was not just one route cause to the troubles facing the women. However, in relation to this specific project, there was a system of complex, interrelated issues that the community had to deal with. Therefore, a more systems approach was taken to understand the problems facing families in Jaltepec, rather than focusing on just

a single issue that needed to be resolved. A summary of the cause diagram is reported in Figure 2C.

4. Define Design Questions

The employment of these two methods allowed the project team to highlight the most important problems facing the women in the community and focus efforts on areas which can lever the most positive impact. These problems were then framed in the form of questions that needed to be solved.

5. Brainstorming

Potential solutions to each of the key problems were brainstormed as a group, with the team building on each other ideas. Similar ideas were then grouped together and the team members voted forward ones which appeared to have the most potential. These best ideas were formed into concept cards.

6-7. Concept Cards and Concept Selection

These concept cards for each problem were compared against each other by plotting them an axis of ease of implementation against highest impact. An example of this process is shown in Figure 3. This tool helped visualise concepts with the most potential and select the most promising concepts to be taken forward to be prototyped.

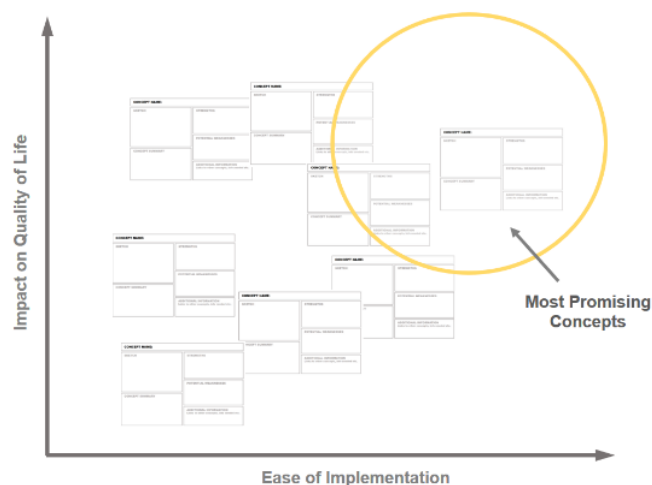


Figure 3. Summary of the Concept Selection Process.

RESULTS & DISCUSSION

The design framework, using the design ‘principals’ (Cross, 2008), helped in the selection process and in highlighting the most potential solution to prototype.

Problem definition

Two of the biggest health impacts facing the community are from indoor air pollution and unsuitable drinking water. By breaking down these two problems through the Causes Diagram (Figure 2C) it was clear that the route of both could be partly traced back to an absence of education, particularly on ‘healthy practices’.



Figure 4. (A) Layout of kitchen with inefficient wood stove design; (B) water quality collected from the local rivers or streams; (C) young girls and women collecting water; (D) poorly designed water storage allowing potential contamination through animals.

Indoor Air Pollution

Inefficient stoves (Figure 4A), time spent cooking, poor working spaces (house structure/kitchen layout) and temperature inversions during cold days all contribute to the exposure to harmful air pollutants. Many of the women in Jaltepec reported cases of eye irritation or pain from the fumes and a number also complained of respiratory or throat problems (Zarza *et al.*, 2017). The World Health Organisation (WHO, 2016) estimates that about 4 million people die prematurely from sicknesses attributable to indoor air pollution (IAP) and that 50 % of pneumonia related deaths of children under five years are caused by cooking with solid fuels.

Access to Clean Water

According to the local government, Jaltepec's main water source is surface- and rainwater, which can be of poor quality (Figure 4B), and no infrastructure for piped water supply is available (Dirección de análisis territorial, 2005). A common activity for women and children is to collect surface water, Figure 4C (Zarza *et al.*, 2017). This collection method is time consuming as it requires walking long distances to reach the water source. A study conducted by UN Water in 45 developing countries around the globe stated that in 76 % of

all households women and children are primarily responsible for collecting water, which can have a big impact on their health and education (UNESCO, 2015).

Time Spent Collecting Resources

Some residents of Jaltepec can spent 2 - 5 hr to collect ~11 kg of firewood every 2 days, and / or in addition similar effort to collect water. Collecting resources is a need rather than a want in rural, poverty stricken communities. Usually women and young girls are subject to carrying out the task of collecting necessities (Zarza et al. 2017). In addition to the impacts on health and education for the children, the daily resource collection has a major consequence for women, who have a reduced ability to generate income. For example; a study done in India by UNESCO approximated that the time women spend on collecting and carrying water causes a national loss of \$160 million USD each year (UNESCO, 2015).

Development of solutions to the key problems

The key aim of this project was to develop solutions for women in the community which would be sustainable. To ensure that the concepts proposed would be suitable, the following approaches were employed to aid with concept generation, selection and development.

Social Sustainability

This study took a socially sustainable approach in identifying, developing and implementing proposed solutions to problems faced by the community. The approach placed emphasis on social participation of the end-users in the process, as well as building capacity so that they can shape their own future (Pretty, 1995; Foladori, 2005). When developing concepts, the aim was to make solutions un-obtrusive, with proposed avenues for training, knowledge transfer and communal integration. Therefore, the solutions should be acceptable, scalable and bridge the gap between early and late adopters (Pine et al., 2011) whilst economically empowering local women.

Gender Focus

In addition to sustainable means of community development, aspects of a gendered innovation approach have been applied to find solutions. As previously mentioned gendered innovations incorporates gender into the aspects of research to produce technology; where gender “*refers to cultural and social attitudes, norms and ideologies that together sanction ‘feminine’ and ‘masculine’ behaviours, products, technologies, environment and knowledges*” (European Commission, 2013). The main aspect of the gendered innovations approach taken in this project is the ‘Engineering Innovation Process’. This method assimilates knowledge about sex and gender into engineering innovation (European Commission, 2013). Engineering innovations could lead to designs that promote human well-being, gender equality, create new products and enhance global sustainability. The Jaltepec women and their exact needs were assessed to produce viable and reliable solutions that could contribute to sustainability and a better life for the women and eventually the entire community.

Concept Generation, Selection and Development

Concepts were brainstormed for each of the defined problems, similar ideas were then formatted as concept cards and then plotted as ‘ease of implementation’ vs ‘impact’, as reported in Figure 3.

For this analysis, ease of implementation was broken down into three factors; the most accepted by community, low cost and low technology development. The biggest impact is measured by: highest impact in quality of life, long term sustainability and most scalable (to other families or communities). The concepts were placed relative to each on this axis, based on extensive discussions as a team. This tool helped visualise concepts with the most potential and select the most promising concepts to be taken forward to be prototyped.

Delivery of solutions to the key problems

Prototyping is a key part of applying design methods and taking a design thinking approach (Seidel and Fixson, 2013). Initially for simply for ‘building to think’ (Brown and Katz, 2011); to try out and explore different ideas, then secondly prototyping for detailed product development. In this stage concepts also underwent user and lab testing to understand effectiveness of the solutions and improved through design iterations.

Three solutions were chosen for further development: a water filter to improve the water quality, a home-made fume-free stove and a carrier cart.

Water Filter

The solution combines sand filtration, a method commonly used pre-treatment for water (Collins, Eighmy and Malley, J.P., 1991) and cloth filtration, a method developed to remove Plankton-Associated *Vibrio cholera* in water supplies in developing countries (Huq et al., 1996). The filter is operated by gravity and can be placed at the end of a gutter ensuring decontamination of water before entering a storage tank or placed in a standalone filter structure allowing to filter water from any other source. For construction and maintenance, the filling material has to be washed and decontaminated to ensure that it is completely free of pathogens, a process that can be carried out by exposing the filling material to sunlight (CAWST, 2009).

Three full-scale prototypes (Figure 5) of the water filter were built to test the effectiveness, ease of manufacture and material composition. A design of two plastic bottles with three different filter media compositions was developed.



Figure 5. Prototypes of the Water Filter

Laboratory analysis was carried out to evaluate flow rate and turbidity attenuation, these being important characteristics of a water filter. Results show the ability of the three filters to reduce turbidity by an average of 97 % (from 73 to 3; 135 to 5 and 280 to 6 NTU). Therefore meeting Mexican’s recommended guideline for drinking water turbidity of < 5 NTU

(Secretaría de Salud, 1994). The filters were also tested imitating a real-life scenario, where the filter is placed at the end of a gutter to clean rainwater harvested at very high turbidity (280 NTU) over time. Turbidity of the water filtered overtime ranged from 10 to 68 NTU, this representing 76 – 96 % of turbidity attenuation. Further analysis will need to be done to test the microbial quality of the water and confirm its viability for human consumption.

Locally Built Cook Stove

The Mexican Government in conjunction with an NGO, the Interdisciplinary Group on Appropriate Rural Technology, disseminated over 600,000 units of a newly developed efficient cook stove, called the *Patsari*, to rural communities in Central-Western Mexico (Berrueta *et al.*, 2015). The stove has been found to be quite successful in communities where it has been distributed, installed and used. However, the current and previous ethnographic findings show that the few recipients of the improved stove in Jaltepec complain about the chimney of the stove as it permits rainwater through the roofs into their houses (Whaites, 2015). The problem seems to arise from improper sealing of the connection formed between the roof and the chimney during the installation process. This has led to some families, to removing the chimney and in some cases their whole stove.

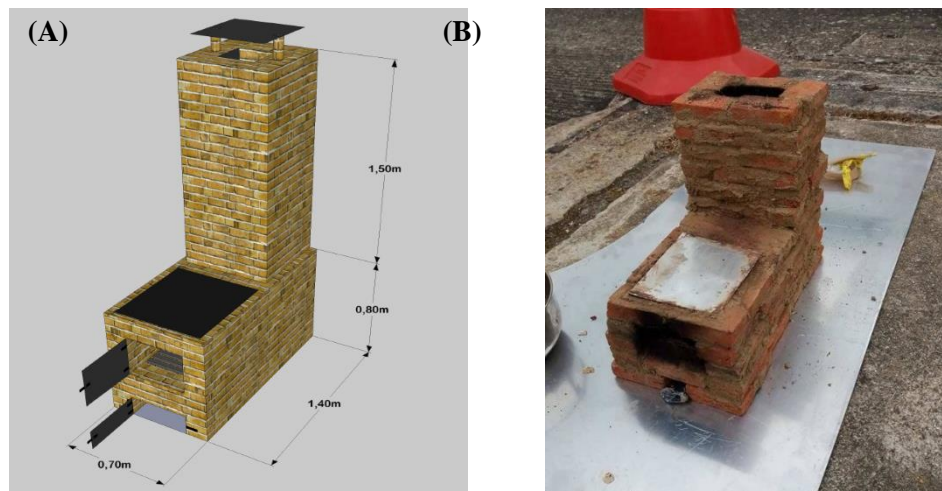


Figure 6. (A) Dimensions of the Improved Cook Stove, and (B) Scale Prototype of the Improved Cook Stove

Based on the *Patsari* stove design, an improved stove was designed to address the problems of IAP that the community is facing. The proposed stove was developed to enable local construction with limited technical knowledge. This design has an inherent flexibility meaning it can be costumed for individual needs. This can potentially increase the acceptance, scalability and dissemination of the improved cook stove in the community. The improved design includes; a door over the combustion chamber of the stove to reduce the possibility of smoke escaping through the opening, a chimney that penetrates through the wall rather than through the roof or a vertical stack with a roof (depending on house structure/type) (**Error! Reference source not found.** 6). To further evaluate the performance of the proposed cook stove, field tests such as; the Water Boiling Test, Controlled Cooking Test and Kitchen Performance Test must be conducted (Bussman, 1988).

Locally Built Cart for Transporting Resources

The concept of a cart able to carry heavy loads over difficult terrain and inclines. Through employing a low centre of mass, balanced over a large central wheel, the weight lifted by the user is reduced, leading to a more ergonomic and easy to use device. A full-scale prototype of the cart was built to test the effectiveness, ease of manufacture and structural integrity. To ensure suitable usability and balance, the prototype also underwent user testing, shown in Figure 7B, involving carrying up to 40 litres of water across difficult terrain.

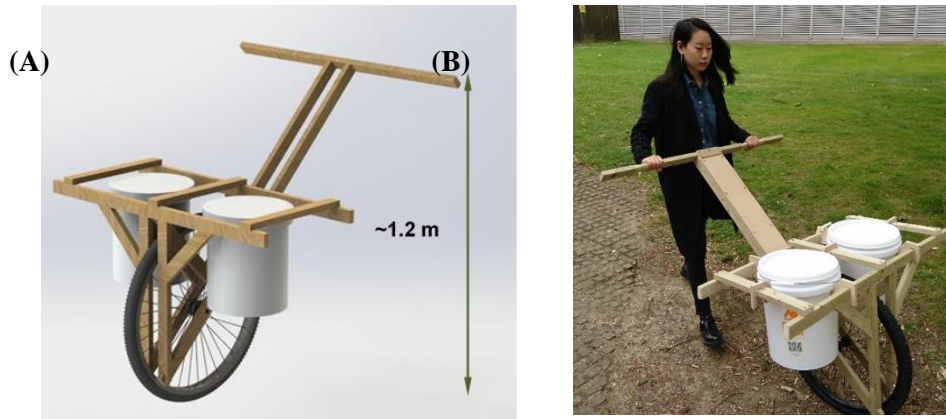


Figure 7. (A) Cart design and (B) Usability testing of the cart working prototype loaded with 40 Litres of Water

Following the prototyping phase, a final cart design was developed based on the feedback from initial user testing, shown in Figure 7A. In line with the overall design approach of this project, the cart was designed to be manufactured locally in the community. It can be made using materials which can be easily and cheaply sourced locally: wood, screws and a bicycle wheel. The dimensions of the cart design are flexible, meaning it can be adapted based on what wood is locally available and it can essentially be manufactured using only a saw, a drill and measuring equipment. A step-by-step guide was developed to aid the community with building the cart.

Overall Discussion

Three technologies were developed into functioning prototypes. All of which were approached in a socially sustainable way; using low cost materials and simple tools. None of the proposed solutions are radical technological innovations, this is based on the criteria for selection of concepts which includes; ease of implementation and acceptance by community. The concepts were built on insights which came directly from the community itself, through the ethnographic study. However, to truly take a design thinking approach, the concepts must be taken to the community in Jaltepec, where they can be prototyped and co-designed to ensure they are addressing the needs sufficiently (Chick, 2012). Borland (2011) argues that this co-design with the end user is crucial to ensure real impact and lasting success. With this view, the final solutions can be described by the term used by Hillgren et al. (2011) as social ‘Infrastructuring’, where concepts can be developed over time in an open-ended way, with active participation of the end users. These concepts, delivered through the community centre can be vehicles to aid further prototyping.

Taking a design thinking approach increases the chances that solutions will be adopted by the desired end-user (Brown and Katz, 2011). This is done by understanding where value needs to be created for the end user, by working directly from end-user accounts and placing that in

the context of the wider system. This user-led approach to rural development contrasts with historic ‘design for development’ projects such as those outlined in the introduction, which can be more tailored to gathering support from western audiences, rather than addressing the nuances involved with everyday life of the community (Borland, 2011).

CONCLUSIONS

The aim of this study was to propose and develop socially and environmentally sustainable solutions to issues, surrounding energy and water faced in the rural Mexican community of Jaltepec. Through taking a multi-disciplinary approach, the myriad of problems that needed addressing were clarified and solutions were ideated, refined and developed. A culmination of design methods (need finding, concept development etc.), and supporting approaches such as social sustainability and women’s empowerment have been instrumental in the selection of key problems and solutions. The engineered solutions such as; the water filter, improved cook stove and cart, used aspects of design thinking to give principal importance to the end user. These proposed solutions are unique to each problem and can be catered to individual needs. Moreover, all the solutions mentioned can be manufactured locally using materials which are accessible to the community.

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Assessing the Feasibility of Solar Microgrid Social Enterprises as an Appropriate Delivery Model for Achieving SDG7

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Abstract

Delivering SDG7 by providing secure access to modern electricity for over 1 billion people globally demands innovation in technology, policy and delivery models. Microgrids, defined as energy generation and supply systems with maximum capacity of 100kW having capabilities of managing local energy supply, are proving a viable solution for remote rural areas in the global South with no prospect of main grid connection. While steady technological progress in the microgrid sector is being observed, effective planning methodologies and delivery models are key to sustainable microgrid implementation. Social enterprise is a collective term for a range of organisations that trade for a social purpose, and offer a niche innovative energy access delivery model that is neither public nor private sector. This paper proposes an evidence-based analysis methodology for assessing the feasibility of a social enterprise delivery model for the deployment of solar microgrids in a developing country. Steps of the methodology include conducting a site-specific feasibility study; assessing the market potential; and business scale-up scenario modelling. Conclusions and recommendations are given on the opportunity for this novel technical and business solution to address energy poverty and achieve SDG7.

Key words: SDG7, Energy Planning, Delivery Models, Solar Microgrids, Social Enterprise

1. Introduction

“Energy is the golden thread that connects economic growth, social equity and environmental sustainability” [1]; however, secure access to modern electricity is lacking for over 1 billion people in the world. This challenge is highlighted by the United Nations Sustainable Development Goal 7 (SDG7): access to clean, reliable, and affordable energy [2], but the scale of the problem inherently demands innovative and holistic solutions for rural electrification. The International Energy Agency (IEA) predicts minigrids will provide 48% of the additional generation needed to achieve universal electricity access by 2030 [3]. A nanogrid, microgrid or minigrid is a term used to describe a network consisting of a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the main grid [4]. The international market for microgrids powered by solar photovoltaics (PV) is on the rise globally, due in part to decreasing costs of solar PV modules and battery storage, as well as advances in auxiliary technologies for microgrid metering, communications, monitoring and control. Innovations in business models and tariff setting have also opened up commercial opportunities for prospective microgrid investors.

Microgrids have the potential to address SDG 7 by enhancing socio-economic wellbeing through improved quality of life, access to public services, job creation and entrepreneurship opportunities and industrialisation enabled by access to energy [5]. However, accelerating solar microgrid deployment demands more than technical research; effective energy planning methodologies and delivery models are needed for rapid and sustainable microgrid implementation. The concept of the ‘energy delivery model’ has emerged to describe a core

set of activities and actors that constitute an energy service required to make energy infrastructure sustainable [6]. It highlights the importance of understanding how to fulfil end-users' needs and the supporting services required to make the energy infrastructure sustainable. The concept emphasises the importance of wider enabling-environment policies, additional supporting services and socio-cultural factors when designing and delivering energy services for low income communities. Traditionally, energy service delivery models have followed frameworks based on public, private, charity or hybrid models with varying degrees of success. The efficacy and sustainability of these approaches to reduce poverty through energy provision varies between models and has been questioned by stakeholders [7], [8], [9] [10].

Broadly defined as the use of market-based approaches to address social issues, a social enterprise provides a “business” source of revenue for civil society organizations [11]. Recognising the need for innovative alternatives to status quo delivery models, social enterprises have begun to fill in the gap between public and private provision of electricity to address energy poverty. However, to date, social enterprises have yet to be explored as serious instruments of sustainability transitions [12], and little research has been conducted that systematically interrogates the dynamics of the sector, its discourses, representations and practices [13].

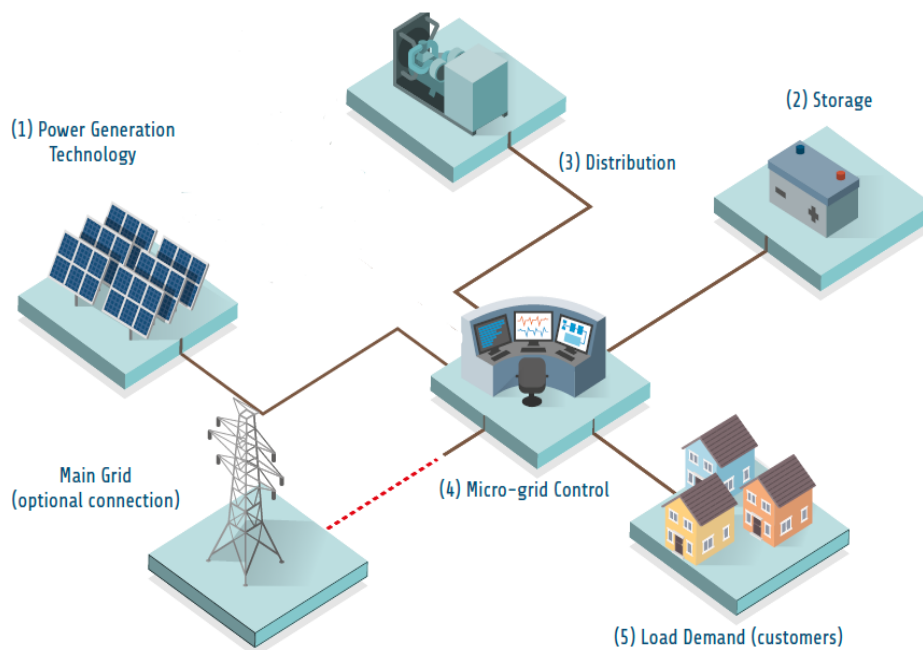
The objective of this paper is to set out the argument for Solar Microgrid Social Enterprises (SMSE) as a conduit for achieving SDG7. Section 2 comprises a literature review of definitions, global trends and advantages of solar microgrids, and introduces the concept of a social enterprise. Section 3 then defines characteristics of an SMSE, an evidence based methodology used to assess their feasibility is outlined in Section 4, before conclusions being drawn in Section 5.

2. Literature review

2.1. Microgrid Definitions and Global Trends

IRENA classifies a microgrid as an energy generation and supply system with maximum capacity of 100 kW having capabilities of managing local energy supply [14], although several definitional exist [15] . As shown in Figure 1, microgrids comprise power generation technology, storage to account for intermittent renewable resources, a distribution grid providing electricity to load demand (customers), and protection and control elements. Microgrids also have the option of interconnecting with other microgrids and connecting to a central grid network.

Figure 1 Micro-grid components Adapted from [5]



According to the IEA, minigrids currently provide electricity to nearly 90 million people and have the potential to serve 212 million people, however to achieve universal electricity access by 2030 the current pace of expansion would have to double [16]. The microgrid market is on the rise globally, mainly due to decreasing costs of renewable energy technologies (specifically solar PV modules) and battery storage [17]. Figure 2 compares solar microgrids to other technologies in terms of tiers of electricity, supply, availability, and indicative use.

Figure 2: Comparing Solar Microgrids to other technologies [5]

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Minimum Supply	0	3W	50W	200W	800W	2KW
Availability (hours/day)	0	4	4	8	16	24
Indicative Use	N/A	LED light, phone charging	Multiple lights, air circulation (fan), television, Phone charging	Tier 2 + small appliances	Tier 3 + medium appliances, water pumping	Tier 4 + large appliances
Indicative Grid Type	N/A	Stand alone	Stand alone	Pico, Nano (Micro)	Nano, Micro	Mini, National

2.2.Solar Microgrids: Advantages and Challenges

Hazelton [18] conducted a preliminary literature review of the benefits and risks presented to communities by PV hybrid minigrid systems. The paper found that the most commonly identified benefits are reduced cost and provision of improved electrical services (more reliable and higher capacity), with opportunity for rural enterprise, strengthened community and local capacity building also cited. Major risks identified included incorrect system sizing due to load uncertainty, challenges related to community integration, inappropriate business models and risks associated with geographical isolation. Further research is required to

identify progress as the technology matures, costs fall and stakeholders learn from previous experience.

Other advantages of microgrids over stand-alone systems include improved reliability and security of supply, economies of scale, improved utilisation factor, load factor, and diversity factor, all leading to reduced cumulative installed capacity, less generation for peak demand compared to that required in a village consisting of highly distributed stand-alone systems, and therefore lower energy cost [5]. Microgrids can contribute to awareness raising and involvement of local communities through development of a common project; allowing the use of higher power electrical appliances and thereby encouraging productive activity. Disadvantages include risk of all customers being disconnected in the event of plant failure, (although reliability issues associated with a microgrid is less than that associated with off-grid stand-alone systems [19]), and more complicated regulatory, organisational and technological organisation than lower power competitors such as solar home systems [20].

2.3.Social Enterprise Definitions

Consensus is growing that human behaviours need to change to a more sustainable paradigm, and alternative frameworks to current public and private sector service provision are being explored as serious instruments of sustainability transition. ‘Social enterprise’ is a collective term for a range of organisations that trade for a social purpose [21]. Several definitions for a social enterprise exist, including:

- “a business with primarily social objectives whose surpluses are principally reinvested for that purpose in the business or in the community, rather than being driven by the need to maximise profits for shareholders and owners [22]”; and
- “organisations who are independent of the state and provide services, goods and trade for a social purpose and are non-profit-distributing [23]”.

Social enterprises exist within the third sector of the economy, aiming to address perceived shortcomings in market or governmental provision of social welfare, and have been acknowledged as a potential driver of social progress [24]. The autonomous nature of the social-economic model applied by such organisations can represent a viable means to reduce state social welfare dependence, and is a proven model for social change [12].

Clear potential exists for social enterprise models to create both social and economic value, while further having an ability to address social and ecological challenges caused by neo-liberal market economies [13]. The innovative business framework is therefore a potential enabler for sustainable development by balancing the three sustainability pillars in social, economic and ecological domains.

Scholarly interest in social enterprise has progressed beyond early focus on definitions and context to investigate management and performance. Within the energy for development sector, delivery model innovation with a social focus has become a key means of embedding energy justice concepts in business models for energy provision [8].

3. Defining Characteristics of a Solar Microgrid Social Enterprise (SMSE)

The purpose of this section is to propose and justify a set of key characteristics for an organisation offering solar microgrids through a social enterprise delivery model such that it supports the delivery of SDG7. The argument presented is based on social enterprise characteristics defined by [25]. With supporting references from literature, these have been adapted and contextualised to consider how SMSEs should define their purpose and strategy.

3.1.Social Purpose

By definition, the primary purpose of a social enterprise is social impact, with commercial activity the means to achieving this. SMSEs should therefore have primary objectives that speak to the social development priorities of the local communities they intend to serve. To enable quantification and tracking of their impact, it is proposed that SMSEs align their social mission within the framework of the SDGs, using methods such as proposed by [26].

Most social enterprises will have more than one objective, with many having goals primarily environmental [27] [28] [29]. Social and environmental challenges are two sides of the same coin, and it is imperative that to maintain a SDG7 contribution SMSE have environmental objectives in their governing documents. Additional to a clear goal of utilising low carbon solar energy in comparison to fossil fuel competitors, SMSEs can go further to monitor, evaluate and reduce their environmental impact. This can be achieved by auditing project carbon emissions (especially from transport), investing in system lifecycle analysis research, and disposing of components such as batteries in a responsible manner.

3.2.Trade Engagement in the Marketplace

The primary revenue source of social enterprises is commercial, relying on market activity from selling goods or services to operate and to scale-up their operations [30]. Many minigrids are examples of one or more organizations that seek to generate revenues by providing a service (electricity) that helps reduce poverty [31]. Other sources of income can include contracts, including service level agreements, usually with the public (or-quasi-public) sector to deliver services [25].

However, due to current legal frameworks and associated lack of feedback on an appropriate and socially accepted tariff structure, minigrad revenue streams are usually quite low and can be insufficient to cover maintenance costs, at least in early stages [32]. Grants and subsidies for initial capital costs can therefore be a key enabler for the successful development of pilot or early stage minigrads [33]. Given the nascent market for microgrids, it is likely the majority of income will come from these donor sources in the short term.

Grant funding can restrict freedom of operations, can foster dependency syndrome [34] and is arguably unsustainable for long-term viability of energy enterprises. SMSEs should therefore accept donor funds for capital or operational costs to pilot microgrids in early stage development, but design a strategy for long-term financial independence through the sale of products and services. Primarily this will be electricity sales, but additional services may include appliance financing, or offering consultancy and technical support to other SMSEs.

3.3.Reinvestment of Profit

Social enterprises target economic sustainability with a wider social mission, reinvesting profits generated to achieve multiple bottom lines [35]. Reinvesting profits ensures operations do not increase personal wealth of those involved and external owners of capital cannot exert control because of their shareholding. Mechanisms can be established to reward workers or customers for efforts in achieving commercial survival and success, however these should not be related to any capital contribution [25].

These restrictions must be clearly defined and adhered to in a SMSE business plan. The business strategy should define a maximum amount of profit which may be used for workforce bonuses and customer benefits, and a minimum amount which should be paid for community benefit. SMSE assets, including accumulated wealth should be held in trust to benefit communities living in energy poverty. Besides the discussion on grants listed above, any capital used by SMSE social enterprise has to be paid for, with debt finance required to be paid with interest as well as regular capital payments, and equity agreements involving deferred payment relating to performance [25].

3.4. Community Engagement and Participation

An emerging trend for communities to take greater responsibility for their own socioeconomic development is evident, and social ventures with a focus on community engagement have the potential to deliver benefits over and above economic outcomes as they closely engage with people with a shared interest in the creation and management of these ventures [21]. Accordingly, participation and empowerment are often forwarded as legitimizing factors for social enterprise [35].

Importantly, for energy focused social enterprises, local people are involved in active dialogue on the future of the energy system for their community, fostering agency, ownership and engagement [36]. New approaches conceptualizing the form of governance for such organisations is essential, centred on ownership, participation and community control [37]; and innovative business models that combine social and community based approaches with entrepreneurship are demonstrating improved sustainability [38] [39] [40].

With such a clear impetus for community engagement and participation in both social enterprises and minigrids more widely, a key aspect of a SMSE strategy should be to recognise the importance of trust, accountability and effective networks in a community, and to invest in developing strong relationships with customers and communities served by the microgrid. Primary goals should be to establish clear communication channels between the SMSE and the community, with mechanisms for bi-directional dialogue to inform change and improve impact and sustainability of the organisation. Options for achieving this include initiating Village Energy Committees, allowing community representatives to engage in democratic processes within the organisation, or exploring options where every customer is a member of the SMSE.

3.5. Organisational Accountability

Accountability in this sense means accounting openly to stakeholders for what the organisation does, primarily to its constituency, or those people whom it affects. Practising accountability requires effective methods of gathering relevant information, consulting stakeholders, reporting on impacts and discussing strategy implications. It also requires the establishment of channels of accountability, the various way through which an organisation engages with its stakeholders and reports on its performance [25].

For an SMSE, accountability should involve transparency on the organisational adherence to the above characteristics, with stakeholders to be accountable to including donors, government institutions and other players in the private sector, while the constituency is the rural communities served by the microgrid. SMSEs should therefore invest in clear communication to the communities they serve and the network of organisations within which they operate. Specific attention and resources should be assigned to monitoring, evaluating, and reporting on the social impacts of the organisation, discussed more in Section 4.3.

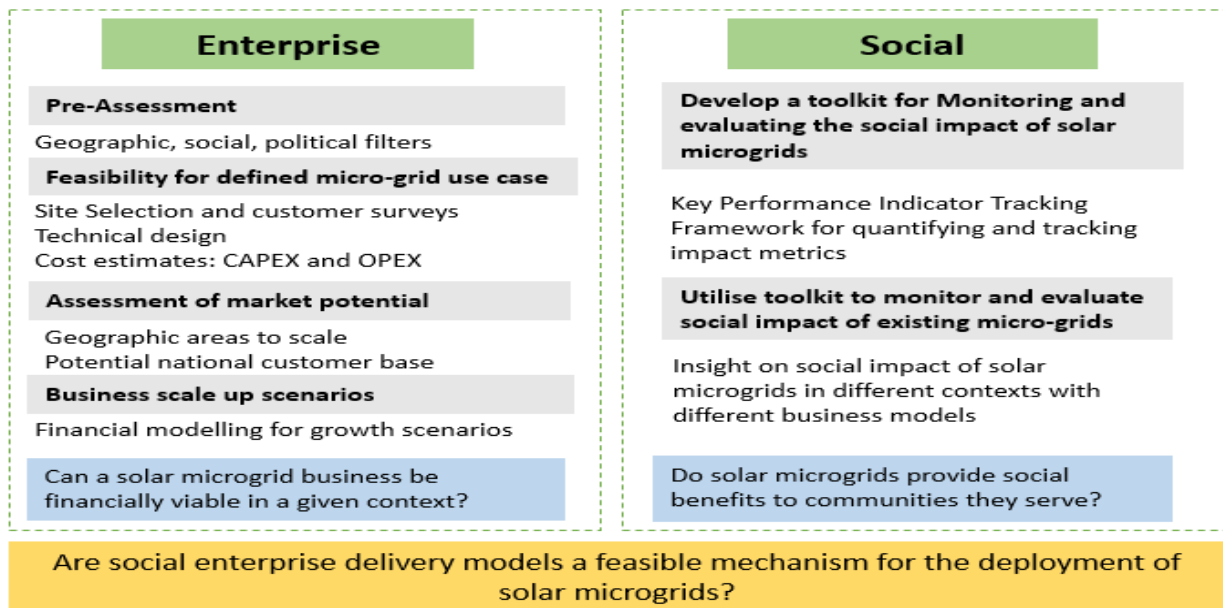
4. Methodology for Assessing the Feasibility of a Social Enterprise Delivery Model for Solar Microgrid Deployment

4.1. Purpose of the Methodology

While the crucial role of business-based approaches within the international development sector is widely acknowledged by academics and practitioners; clear insight into what constitutes a viable business model in environmental, social and economic terms, remains unresolved [41]. Having outlined defining characteristics of an SMSE, a methodology is needed to establish whether a social enterprise delivery model can be a feasible means of achieving SGD7 through offering secure, reliable and affordable electricity to rural communities in a sustainable manner. This section proposes such a methodology, in two

parts: firstly, to determine the financial viability of a SMSE; secondly, to determine and quantify the level of social impact delivered by SMSEs to the communities they serve. A summary of the methodology is shown in Figure 3, while key steps are discussed below.

Figure 3 Methodology summary



4.2. Assessing the Financial Viability of a SMSE

To ensure organisational sustainability over a timeframe sufficient to achieve the desired social purpose, a SMSE must be financially viable (defined here as ‘profitable’, or earning enough income to cover ongoing organisational and project costs with a surplus to re-invest in the organisation). This section of the methodology determines the financial viability of a SMSE at various scales.

4.2.1. Pre-Assessment

A filtering exercise is required to assess whether solar microgrids should be considered as a potential technology for rural electrification in a given geographical location or context. Indicators such as level of grid access, solar resource, population density, and current country-level progress towards SDG7 are considered, and if certain criteria are not met, resources should not be invested to continue the viability assessment.

4.2.2. Feasibility Study for Defined Use Case

A site-specific feasibility study to determine an indicative system design based on realistic user demand is required to output local costs of developing, installing and maintaining a solar microgrid. Use case economic data of CAPEX and OPEX and comparison of indicative tariffs with customer ability and willingness to pay act as indicators of microgrid feasibility. If the business case for one microgrid is deemed profitable, and tariffs affordable, the economic data gained from the use case feasibility assessment can be utilised in subsequent steps of the methodology to assess the market potential and conduct business scale up modelling at a national or regional level for SMSEs.

The proposed method for system design and business planning has been trialed [42]; it builds on industry standards [43] [44] and employs two key elements:

- a qualitative site selection and customer survey exercise, utilising enumerator fieldwork to provide metrics for project feasibility; and
- a quantitative techno-economic modelling, focusing on technical and financial feasibility to inform a viable business model.

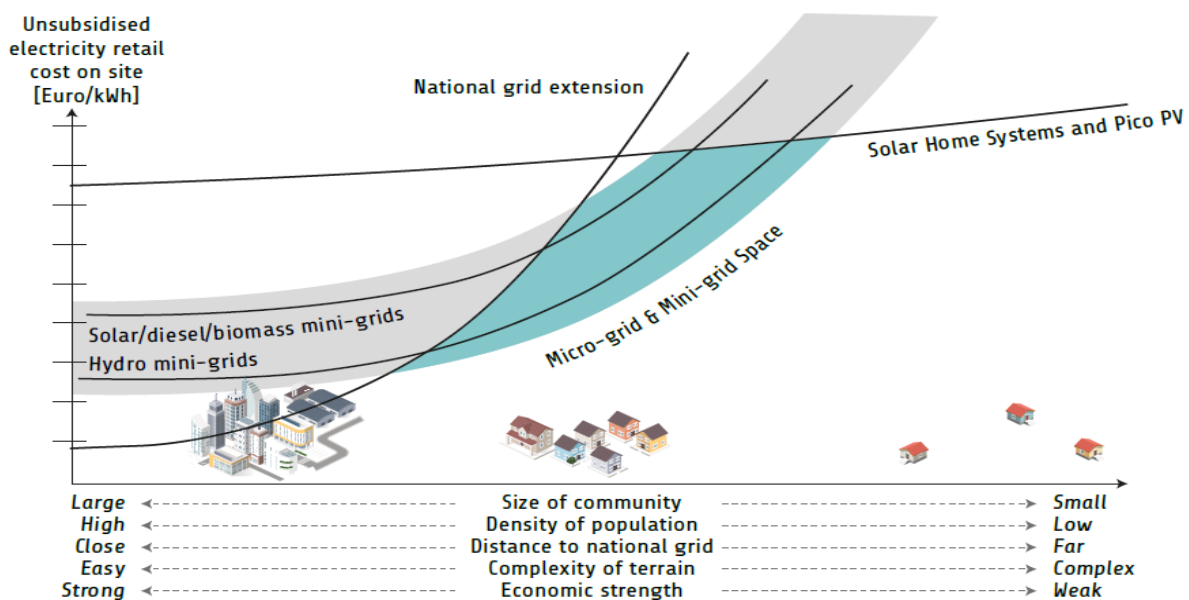
Effective system design and business planning for solar microgrids relies on confidence in expected demand and demand growth of target communities. In areas without an existing electricity supply, load profiles and demand growth suffer high levels of uncertainty [45]. The methodology utilises demand data estimates derived from data captured from customer surveys, national census data, and published demand datasets from microgrids in close geographic proximity.

4.2.3. Assessment of Market Potential

Market assessments are widely seen as being key to the planning stages for off-grid energy provision in the developing world [46]. Acting as a high-level feasibility study, a market assessment indicates the size of the potential consumer base for a technology, along with their distribution within a given region and the necessary considerations of the economic viability of projects at specific locations. Market assessments also map regulatory, political, cultural and socio-economic factors that impact sustainable deployment.

Figure 4 illustrates how parameters related to the geography, density and size of communities also influence the choice of energy access solutions [47]. Such parameters need to be investigated to determine a potential microgrid market size, essential for establishing the business viability of a SMSE.

Figure 4 Micro/Minigrids Space Compared to Alternatives [47]



This part of the methodology assesses the market potential at a national or regional level for SMSEs. The output defines where in a country or region solar microgrids are cost competitive with alternatives, and maps out the regulatory, institutional and economic ecosystem in which implementation will occur. The market assessment quantifies the potential for scaling operations, based on outputs of the use-case feasibility study and is an essential step to evaluate the viability of a SMSE, informing organisational strategy.

4.2.4. Business Modelling for Scale-Up

Based on outputs from the two preceding steps, further modelling investigates business growth scenarios for SMSEs, assessing in detail SMSE financial sustainability by balancing costs of installing and operating microgrids with income from sales of electricity. The financial modelling incorporates economic outputs of the use-case microgrid feasibility assessment, with scenario modelling used to investigate organisational cash flow forecasts through different levels of deployment to fulfil the regional or national market potential.

The ultimate objective is to determine the financial sustainability of the scaled SMSE, but to do so with consideration of the defining characteristics outlined in Section 3. For example, as well as investigating economic implications of the effect of reduced CAPEX through bulk purchasing of materials, the increased costs of monitoring social impact and enhanced community engagement activities must also be factored into the financial modelling.

4.3. Assessing the Social Impact of SMSE

The social enterprise value proposition centers on providing social benefits to communities. Currently there exists a paucity of recorded evidence of the impact microgrid systems have on the general wellbeing or social infrastructure of communities they serve, with reporting generally focused on measuring technical and economic performance of installed systems [48]. It is also recognised that measuring energy access impact needs to go beyond numbers of electricity connections and products sold, to an approach that assesses how effective that energy service is [49]. Following the first methodology pillar to determine financial sustainability, the second therefore centers on forecasting, planning and measuring increased social impact of SMSEs through a Key Performance Indicator (KPI) framework.

KPIs evaluate the success of an organisation or of a particular activity (such as projects, programs, products and other initiatives). Used as part of a Monitoring, Evaluation and Learning strategy, they can form the basis of tracking social impact of a microgrid initiative. KPIs are quantitative or qualitative methods, chosen to assess the scale and rate of progress of an intended social goal [50].

A template KPI framework has been developed [50] that can be used as a monitoring and evaluation tool by SMSE practitioners. A dashboard contains a variety of social impact indicators that practitioners can track, such as increased uptake of productive uses of energy, or impact on gender, education and health. Columns for planned versus actual performance against each indicator at certain milestones allows tracking of the overall microgrid performance. To test the hypothesis of enhanced social impact through a SMSE, the KPI framework must be utilised to gather primary data from an active SMSE with identical indicators gathered from a solar micro grid operation governed by a private or public sector framework for comparison.

5. Conclusion

Solar microgrids have the potential to address multiple SDGs by enhancing socio-economic wellbeing through improved quality of life, access to public services, job creation and entrepreneurship opportunities and industrialisation enabled by access to energy. Their efficacy in achieving the challenge of SDG 7 specifically is largely dependent on the sustainability of the delivery model used to implement them. Private sector initiatives are showing promise to accelerate deployment of the nascent technology, but a purely profit driven approach is unlikely to deliver for the most vulnerable of society, as is the focus of the SDGs. Governments in developing countries are by nature better suited to large infrastructure electrification programs and are generally ill-equipped with the business innovation expertise required for effective and impactful solar microgrid delivery. Social enterprises, with social and environmental goals hard-written into their constitutions, therefore have high potential for delivering solar microgrids with increased social impact and increased sustainability, offering a robust mechanism to achieve SDG 7 in the Global South.

However, understanding the impact solar microgrids operating under a social enterprise framework have on the SDGs is still limited, and this emerging concept needs to be implemented and monitored appropriately to build an evidence base for its value or otherwise. This paper has presented the concept of a Solar Microgrid Social Enterprise, proposed a set of general characteristics that define the social and enterprise aspects with

respect to solar microgrids, and has outlined a specific approach for assessing the feasibility (ensuring appropriate implementation) and monitoring impact (building the evidence base). The feasibility methodology includes pre-assessment, feasibility for a defined use-case, assessing market potential, and business modelling for scale up, while the impact evaluation methodology proposes a KPI framework to monitor and track social impact.

Although an argument for enhanced organisational sustainability and increased social impact through SMSE is justified here, data is required to test the hypothesis, proposed through piloting SMSEs and monitoring their performance and impact in comparison with public and private sector microgrid delivery models. The research presented has significance for practitioners and researchers exploring alternative sustainable delivery models for energy service provision in developing countries, however further research is needed to validate the methodology and to draw insight into the potential SMSEs have in contributing to SDG7.

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AGGREGATORS - A PROPOSAL TO MAKE DISTRIBUTED GENERATION IN RURAL SETTLEMENTS PROFITABLE

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ABSTRACT

The use of electricity significantly improves the life quality, especially in remote areas. By using electricity, it is possible to read after the sunset, take a hot bath, keep the food cool to preventing them quickly rot, etc. Although energy supply can be considered basic needs, in places like rural settlements in developing countries, sometimes it is not available or the quality of this energy is significantly lower when compared to urban areas. This reduces the possibility of uses, e.g. if the energy is used for cooling down milk, being without energy for a couple of hours can compromise the entire production.

The energy supply in rural settlements can be classified into three categories:

- **Good power quality:** power quality of the settlement attends to the requirements, e.g. the availability and electrical characteristics (frequency and voltage magnitude) are sufficiently close to the requirements.
- **Regular power quality:** energy is available most of time but it does not attend to the standards.
- **Poor power quality or not available supply:** under this condition, most of time the energy does not fulfill the standards or is not even available.

For each one of these scenarios there are some priorities to fulfill. For the first one (good power quality), for instance, the focus must be in the improvement of the efficiency and, if possible, in local generating power. In the second scenario, efforts must be made to improve the power quality, reducing/minimizing the periods without energy and attending to the standards. For the third situation, actions must be taken to making energy available.

Considering that a settlement has potential for power generation, since biomass, wind, small hydroelectric, solar primary energy is available, often there is a latent potential for energy generation that is not being taken advantage. The challenge is to proposing a model that can be profitable and which does not change dramatically the lifestyle of the people who lives there. In this model, an aggregator will be responsible not only for the commercial, but also for technical and social issues. If there is energy available from the prosumers, the aggregator will buy it from them, storage and sell it when it is more profitable. The investments required for both power generation and for storage, often can be too high for individual who normally are poor people.

In this model, resident of rural settlement either produce biomass or lease the area to be used for power generation and share the profits with the aggregator. Since the energy in rural settlements is usually cheaper than in urban areas due to subsidies, it is important to be aware against speculative market for electric power, i.e., buying power from the grid when it's cheaper and selling it back to the network when it is at a higher value, without generating.

Another factor that makes this model interesting is use of renewable energy. There has been a major concern in reducing the use of fossil fuels. Thus, this kind of project can receive more incentives if energy sources are renewable.

Keywords – Distributed generation, budget savings, making profit with energy.

I. INTRODUCTION

Seeking new ways to commercialize the electricity in a network that continually goes through changes, there is the aggregator. The concept of aggregator refers to a negotiator who would be responsible for the purchase agreements and sales of energy of a prosumers group. Such agreements may be performed either in the energy market or directly to the utility responsible for the prosumers area.

The aggregator can be a company specializing in energy trading or a cooperative formed by several prosumers. In Fig. 1 shows how the aggregator connects the microgrids and the utility, as well as the energy market.

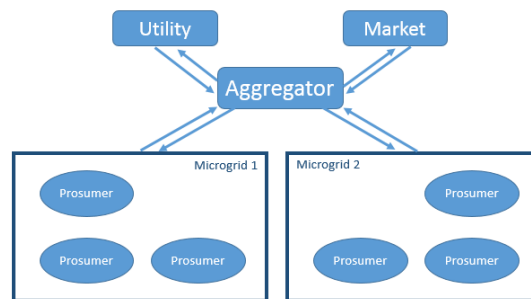


Fig.1. Aggregator and Microgrid Model.

Usually the model consists of prosumers who own their own source of power generation and the surplus they can sell to the utility through an aggregator.

Besides making the negotiations for the purchase and sale of energy, the aggregator may also be responsible for the investment of power sources suitable for the location e.g. the photovoltaic panels could be paid by the aggregator and the prosumer would pay less for electricity [3]. This model becomes interesting especially for consumers who do not have the capital needed to make a big investment.

The application of these concepts becomes interesting for a rural community because there is the certainty of supply at times that there is a grid failure, which are really common in Brazilian rural areas, improving the power quality and also generating a profit due to the sale of energy.

II. PROSUMERS IN BRAZIL

Currently, some consumers can sell freely in the market the electricity they produce and are known as free consumers. However, to fit the profile of these consumers, several prerequisites in the legislation must be respected. These consumers are, e.g., industries, shopping malls and power plants.

Brazilian regulations allows the consumer to produce electrical energy from photovoltaic panels and that the surplus can be injected into the grid. While providing power to the system, the consumer does not receive a monetary return. According to the RN 482 by ANEEL, when the consumer generation is greater than the consumption the difference is converted into credits to be used by the consumer for up to 36 months [4]. There has been a need to change

the legislation to allow groups of consumers to use the production of electricity as a source of income, especially those located in rural communities as settlements.

The model proposed by this paper would be to change the law, allowing prosumers, which can be seen as a microgrid, to produce electricity and sell it through an aggregator, to the utility or directly in the energy market, seeking the most lucrative business. The power sources of prosumers can be centralized in one location near or connected directly to each prosumer, depending on availability. It is due to conduct a study to determine which sources should be used and how much needs to generate to make the business profitable while suppressing the consumption needs of the microgrid.

This kind of application can be used not only in Brazil, but also in several countries that need to offer better power quality to their rural areas and provide an alternative to the consumers that live in those areas to use their natural resources to produce energy and sell it. With more energy sources the utility can provide more and better electricity to the grid.

III. DISTRIBUTION NETWORK CHARACTERISTICS

According to [5], transportation costs make up a quarter of customers' electric bills, and in Brazil 75% of this amount is due to energy transportation through distribution network.

Sending energy from a point to another implies in solve some problems like, make sure that the system has the capability to do so, i.e. there is a stable point of operation to send this amount of energy. In this first scenario, one can say that the only concern is to deal with the losses involved in the process. Of course, the computation of these losses will affect in the electricity price after all.

One second possible scenario is the system does not have a stable point of operation to send the required amount of energy, which implies the need of structural changes on it, otherwise some loads could would have no energy supply.

In Brazil the cost of energy, not supplied (CENS) is a parameter widely used for optimizing investments in network quality [6]. The regulatory agency establishes standards, which have to be followed by the utility, otherwise a fine may be applied.

While an interruption may last only a few seconds, some industrial processes may take hours to be restarted, making the costs related to this short interruption expressive, as shown in [6]. In a settlement that is characterized by the production and sale of milk, when a power quality problem is responsible for the malfunction of refrigeration equipment used to store the product, there is a large monetary loss due to the product that is damaged in the process.

Several solutions may be applied in a system, which has some of those conditions, make the transmission and distribution system more efficient and reliable, by adding more transmissions and distribution lines, transformers is one possible solution to improve power quality. Of course this kind of solution is one of the most expensive one. Other possible action is to introduce FACTS in the transmission line, improving the voltage level and margin of stability, making possible increase the range of operability of the system.

Another possible solution is the implementation of distributed generation in this system, thus makes it possible to not only reduce losses from transmission and distribution, but also increase the amount of energy available in the system, this extra energy, when not needed, can be exploited by aggregators.

In rural settlements is significantly the share of residents living in rural work, such as planting, breeding among other characteristic that location services. The bagasse from sugar cane for example can be used to generate electricity by burning it. Other by-products of rural

activity can also be used to generate electricity, such as the use of bio digesters, using the excrement of animals to generate electricity.

The natural resources present in the area also can be used to generate energy, solar, wind and small hydroelectric are examples of natural and renewable sources that can be used. Of course, each rural settlement will have one best solution in terms of cost and benefits, making necessary a more detailed analysis before the proposition of some form of generation.

IV. THE SUPPLY RENT MODEL.

The investments required for both power generation and for the storage, often can be too high for individuals. In rural settlements usually generally live the poor, making it difficult to implement the concept of prosumers.

On the other hand, often there is a latent potential for energy generation that is not being taken advantage of, potential that this could reduce transmission losses or for example prevent a very important process running out of power during a fault.

In this model then we have the resident of the rural settlement to lease the area to be used for power generation and therefore receive a portion of the profits involved.

Whereas the price of electricity for this consumer class is significantly smaller compared to urban areas, it is proposed that the locally generated energy is mainly managed by the aggregator.

Once the energy in rural settlements is cheaper, you should take care that it does not create a speculative market for electric power, i.e., so others do not create companies specializing in buying power from the grid when it's cheaper and sell that energy to the network itself when it is at a higher value. While this idea is valid, since it considers the law of supply and demand, the speculative market model can significantly change the marked and load curves as it could be created new peak hours due to this speculative market.

For this system brings benefits to the grid, it is interesting that the power purchase of own network to sell it again when cost more to be regulated by a competent authority, thereby avoiding a significant distortion in the load curve a particular region.

So because of price issues, the implementation of aggregators in rural areas need not only technical skills, but also legislative and regulatory care since it is a scenario does not yet exist.

Another factor that makes this model interesting is the question of the use of renewable energy sources electricity. There has been a major concern in reducing the use of fossil fuels. Thus, this type of project can receive more incentives if energy sources used are renewable.

V. ECONOMIC ANALYSIS

The Brazilian Scenery has been presenting unfavorable conditions for microgeneration introduction when the scenery owed normative currently not to allow that if financier could have an immediate return, so the compensation is used for credits in discount future.

At present the return of the investment of the investor has been by it if ruled in the compensation of the usually fulfilled consumption and transfer of eventual excess for another consumer regularly connected in the net of distribution of electric energy. The model normative Brazilian does not favor the elements use creators as fountain of income and incitement of new straight business.

In this sense, a new model normative must be thought to compose attractive conditions to the potential interested ones in becoming energy producers and subsequently there in nets of distribution of the dealership of distribution. This is inevitable there rethinks in a model production of energy of way decentralized without disposing of a straight regulation of the regulating agency ANEEL. In this sense, the remuneration base of the dealerships of distribution starts to be a basic element in the composition of a proposal that could be seen as an alternative to promote a return quicker of the investment.

If they thought that the equipments creators could make part of the base of remuneration of the dealerships of distribution, the assets contained in the properties of the clients and used for decentralized generation, they would start to compose the values of tariff adjustment that are modelled and gone over again to the clients. With the proposal of the model, the decentralized producers – through the dealership of distribution – would start to receive a proportional value of the values derived in the tariff adjustment.

Such a model can provide profits for the three stakeholders wrapped in the proposal: the final client, as soon as with the decentralized production it will be able to provoke a better quality in the distribution of the energy received in his point of coupling of load – this factor that can be used like justificatory argument for the elevation of the values of the tariff; the producer of energy that can realize an acceleration in the return of the investment of the equipments destined to decentralized production – promoting in this way the appearance of new business originating from the change; and the dealership of distribution that will amplify his remuneration base before to the regulating organ and also one will provoke postponement in the investments in strength of the electric system due to approximation of the generation of his consumers.

The figure of the aggregator in this sense also might promote the link of connection and negotiation between the producers and the dealership of distribution, as soon as there will be changes in the quantity of equipments creators as well as his characteristics. From a model normative better definite, to fulfill it of functions of this figure will be able to act in a way of answering the interests of his represented ones.

The economical model presents bigger viability when applied in rural zones due to the compound of benefits demonstrated by the set of interested parts and the biggest amount of retardation of investments by part of the dealership of distribution.

VI. CONCLUSIONS

The contribution provided by this paper is to introduce an application model of aggregator concepts and microgrid in a rural community as settlements. Interestingly, these concepts can be applied without consumers perform large investments, since the aggregators would be responsible for the installation and maintenance of the energy sources. Thereby consumers start to generate energy locally with better quality than that provided by the utility and consequently pay less for consumption.

It should be emphasized the importance of studies to determine which are the best sources of electricity for each case, for each rural community has different resources. Also, it's very important to regulate and supervise such models so that consumers receive some return with the installation of these systems and are not treated improperly.

The microgrid model managed by an aggregator has great potential to help both the network and consumers of the microgrid. It would be possible to supply the growing demand for energy without the need to build large and expensive generating energy sources. Distributed generation located in microgrids assists in energy supply, especially in times of

failure in the network. Thus, it follows that the model presented in this paper may be a solution to the energy needs of rural communities while helps the network to provide more electricity.

ACKNOWLEDGEMENTS

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Appendix 1: Conference Programme

International Conference on

Energising the SDGs through appropriate technology and governance

Organised by the Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK

4-5 July 2019

Venue: Queens Building Main Auditorium 1.10
De Montfort University, Leicester LE1 9BH

Programme

Day 1: 4th July 2019

Opening session (QB1.10)

9AM – 9.30AM: Registration

9.30-9.35 AM Welcome by Prof. Subhes Bhattacharyya

9.40 – 10.45 Keynote speech: **Optimistic Futures: Designing for Sustainable Living**, David Kester, Managing Director, DK&A and Design Thinkers Academy, London

10.45- 11.00 Tea break

Parallel Sessions 1 and 2: 11.00 to 12.30

Session 1: SDGs and the cities (QB1.10 – Main auditorium)

Session Chair: Dr. Andrew Mitchell, IESD

11.00 – Integrating the SDGs into Urban Climate Plans: Insights from Japan, Eric Zusman, Ryoko Nakano, Matthew Hengenbaugh, Tetsuro Yoshida, Fernando Ortiz-Moya, Institute for Global Environment Strategies (IGES), Japan

11.20 Analysing climate action plans of selected UK cities for the SDG alignment, Subhes Bhattacharyya, Birgit Painter and Leticia Ozawa-Meida, IESD, DMU.

11.40 -12.00 Regional Circulating Economic Sphere and the SDGs – Fernando Moya-Ortiz, IGES, Japan

Q/A 12.00-12.30

Session 2: Energy access and the SDGs (QB 0.10)

Session Chair: Dr. Rupert Gammon, IESD

11.00 – 11.15: Experiences from solar PV rural businesses in Malawi, Damien Frame, Peter Dauenhauer, Aran Eales, Stuart Galloway, *University of Strathclyde, UK*

11.15 –11.30: Overcoming the bottleneck of weak grids: Reaching higher tiers of electrification with SHS for increased supply reliability, Martha Hoffmann, Setu Pelz, Philipp Blechinger, Reiner Lemoine Institute, Berlin/Germany

11.30 – 11.45: Maximizing the penetration levels of hybrid renewable energy systems in rural areas with demand side management approaches in achieving SDGs, Lanre Olatomiwa and Richard Blanchard, Loughborough University, UK.

11.45-12.00: Policy coherence to enable effective energy strategies and promote sustainable development: toward developing an integrated simulation model for Nigeria, Adedoyin Adeleke, Fabio Riva, Francesco Tonini, Emanuela Colombo, Politecnico di Milano - Department of Energy.

Q/A session 12.00 – 12.30

Lunch and networking 12.30 -13.30

(Queens Building Foyer)

Poster presentations

Parallel sessions 3, 4, and 5 : 13.30-15.00

Session 3: Urban architecture and the SDGs (QB0.09)

Session Chair: Dr. Adriana Laura Massida, Institute of Architecture, DMU

13.30-13.50 The circular economy in architectural design as a contribution to achieving the SDGs: Opportunities and strategies for urban construction and demolition processes, Massimiliano Condotta and Elisa Zatta, Università IUAV di Venezia, Italy

13.50 – 14.10 Vernacular architecture as a resource for resilient communities, Codina Elena Dusoiu and Tana Nicoleta Lascu, UAUIM, Romania.

14.10-14.30: Solar and geothermal energy for low-carbon space heating and energy independence, Evangelos I. Sakellariou, Andrew J. Wright, Muyiwa A. Oyinlola, IESD

14.30 – 15.00 – Q/A session

Session 4: Renewable energies and the SDGs (QB 1.10)

Session Chair: Dr. Richard Snape, IESD

13.30 – 13.50 An empirical study of the variation of electrical output from photovoltaic-thermal solar panels, Rick Greenough, IESD

13.50-14.10 Biomass energy potential in rural communities, Bruno Medeiros Coelho; Dionízio Paschoareli Júnior, UNESP, Brazil

14.10 – 14.30 Integrating solar to ground seasonal heat storage for the small domestic heating sector in the UK: Experiments from a research prototype, Carlos Naranjo-Mendoza; Richard M. Greenough; Andrew J. Wright, IESD

Q/A session 14.30-15.00

Session 5: Water and health issues in the SDGs (QB0.10)

Session Chair: Dr. Kutoma Wakunuma, Centre for Computing and Social Responsibility, DMU

13.30-13.50 Barriers to Monitoring Water and Sanitation delivery by NGO's:

Case Study Ghana, Hikima Jewu, Health and Life Sciences, DMU

13.50-14.10 –Sustainable development and water conservation practices in South Africa, Djiby Thiam, University of Cape Town, South Africa

14.10-14.30 Achieving sustainable development goals with an R&D prize platform for neglected diseases, Brigitte Granville and Eshref Trushin, UCL and DMU

Q/A session 14.30 -15.00

Tea break 15.00-15.30

Panel Discussion: 15.30 – 16.30

How can technology and governance support the Global Goals?

Panellists: Prof. Mark Lemon (IESD), Prof. Richard Werner (Business School), Dr. Eric Zusman (IGES), Dr. Maurizio Sajeve

Moderator: Subhes Bhattacharyya

End of day 1

Day 2: 5th July 2019

Session 6: Presentations from a distance (QB0.10)

Session Chair and facilitator: Dr. Andrew Reeves (IESD)

9.30-9.50: Energy Access through cross-border electricity trade: Pathway to Achieve SDGs in South Asia, Rohit Magotra, Shababa Haque, Asha Kaushik, Jyoti K. Parikh, IRADE, India

9.50-10.10 - What determines uptake of modern fuel: A case study of India, Pooja Sankhyayan and Shyamasree Dasgupta, Indian Institute of Technology, Mandi, India

10.10-10.30 - Analysis of Brazil's funding structure designed to meet the Sustainable Development Goal 7 targets, Clarice Ferraz, University of Rio de Janeiro, Brazil

Q/A session 10.30-11.00

Tea Break 11.00-11.15

Parallel session 7 and 8: 11.15 -12.45

Session 7: Tools and evaluations (QB 1.10)

Session chair: Prof. Rick Greenough (IESD)

11.15-11.35 A SUSTAINABILITY COMPASS to help innovations and policies heading towards SDGs, Maurizio Sajevo, Finland

11.35-11.55 Is this working? Evaluating solutions for sustainable communities, Andrew Mitchell, Mark Lemon and Andrew Reeves (IESD)

11.55-12.15 A survey informed propositions for identification, salience and co-option of stakeholders for steering the SDGs in Sub-Saharan African Countries, Muhammad Abubakar (IESD)

Q/A session 12.15-12.45

Session 8: Business solutions to address the SDGs (QB 0.10)

Session chair: Prof. David Rae, Director Centre for Enterprise and Innovation (DMU)

11.15- 11.35 Women centred empowerment: developing solutions to improve living conditions in rural Mexico, Wastling, T., Sebastiampillai, S. , Liemberger, M., Dubreuil, X., Escamilla Greenham, P. , Mrzilek, J., Okpala, E. , Xue, J., Villa, R., Simms, N. and Encinas-Oropesa, A, (Cranfield and DMU)

11.35-11.55 Assessing the feasibility of solar micro-grid social enterprises as an appropriate delivery model for achieving SDG7, *Aran Eales, Scott Strachan, Damien Frame, Stuart Galloway*, Strathclyde University

11.55-12.15 Aggregators - A proposal to make distributed generation in RURAL settlements PROFITABLE, Mariana Costa Falcão; João carlos Pelicer Jr ; Luiz Otavio Manhani Machado ; Dionízio Paschoareli Júnior (presented by Bruno Medeiros UNESP), Brazil.

Q/A session 12.15-12.45

Lunch 12.45 - 13.30 (QB0.09)

Afternoon session: 13.30- 16.00

Workshop on SDG Compass (QB 1.10)

Facilitated by Dr. Maurizio Sajeve

End of conference

Appendix 2: List of participants

Speakers / Poster presenters	Organisers	Other participants
David Kester	Subhes Bhattacharyya	Hannan Amoozad Mahdiraji
Muhammad Abubakar	Rupert Gammon	Sylvia Delpratt
Adedoyin Adeleke	Mohammed Haseeb	Mayen Cunden
Asma Alahmed	Salisu Isihak	Ayesha David
Richard Blanchard	Mark Lemon	Ahmed Aburannat
Bruno Coelho	Ljiljana Marjanovic-Halburd	Will Blackshaw
Massimiliano Condotta	Birgit Painter	Mauricio Belaunde
Matthew Hegensbaug	Nittalin Phunaphai	Damian Eke
Martha Hoffmann	Andrew Reeves	Sheridan Few
Hikima Jewu	Richard Snape	Valeriy Izyurov
Tana Nicoleta Lascu	Paranee Sriromreun	Oluwatobi Karim
Andrew Mitchell	Parkpoom Sriromreun	Daniel Kerr
Ryoko Nakano	Kutoma Wakunuma	Jinjin Lou
Carlos Naranjo-Mendozaa	Richard Werner	Ashely Morton
Paloma Ortega Arriaga	Lyn Wongwattanasiri	Eunbin Nam
Fernando Ortiz-Moya	David Rae	David Notman
Eric Zusman	Adriana Laura Massidda	Janet Riley
Leticia Ozawa-Meida		Mohammed Zainab
Maurizio Sajeve		Geoff Smith
Evangelos Sakellariou		Ahmad Taki
Djiby Thiam		Sekyen Fwangwet
Eshref Trushin		Adel Hatamimarbini
Raffella Villa		John Kriper
Tetsuro Yoshida		
Elisa Zatta		
Rohit Magotra,		
Asha Kaushik		
Pooja Sankhyayan		
Clarice Ferraz		

Rick Greenough Stuart Galloway		
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Appendix 3: Feedback on the event

What did you like about the event?

I thought the programme was organised very well.

The subjects discussed

The diversity of speakers and themes.

The discussion and dialog . Getting the perspectives of the different speakers and attendees.

*Wide range of topics *New perspective of "design" aspect *Inspiring discussions

*Atmosphere

Focus on SDGs and opportunity to discuss how different factors inter-relate when trying to further progress towards them.

A strong mix of international colleagues and a range of papers presented.

Good discussions - great keynote and nice international audience

interdisciplinarity, perfect timing

Very interesting presentations

The wide range of topics covered.

Meeting people who are involved in similar research areas

it was a very good platform that allows academics, policy-makers and practitioners to interact and exchange ideas.

The high level of scientific presentations including experiences from ALL OVER THE WORLD.

Possibility to include also the Skype presentations. The very prompt dissemination of presented papers. Extremely good communication during all period since the event has been launched

Discussion part after the presentation. Everyone share many ideas and comment the useful things.

What did you dislike about the event?

Unfortunately the presentations from abroad were very difficult to comprehend. Perhaps using Skype instead of another software might have gone better. Or just a normal telephone connection.

The technical problems with the online speakers

Nothing, but in future conferences, it might be advisable to organise a dinner event where people can network and socialise.

The Parallel sessions. Having to chose between two presentations that were both equally important.

*Website not working, no programme available in advance *Session head unorganized, better if they start presentation/recording *Video call quality very hard to understand

*Presentation time changed from 20 to 15 minutes

Could have been more radical - there was a lot of discussion of small scale interventions, which are laudable, but little discussion of systemic change. No need for yet another re-usable cup! If we get one every conference, that's probably worse than the problem they're supposed to solve...

Nothing comes to mind

Nothing

probably a larger audience would have helped to get even more results and feedbacks.

It was pretty good overall.

It was on the smaller side
I missed the visit tour of the university

Was there any information that would have been helpful to know before the event?

Nothing in particular
From a DMU staff perspective, I think everything was clear, but I am unsure if participants from other institutions might need further information.
No, most of the information was shared prior to the event.
*Programme *Recommended hotel to stay
Would have been nice to see program earlier and have it available - possibly on a conference app if we wish to avoid paper.
Perhaps final joining instructions, but otherwise all was fine.
More information on speakers, perhaps some of their previous work or current projects
A map indicating the pedestrian route new walk from train station to the city centre . It was lovely passing there the last day I went back to the train station..lots of events..music..birds...children through the rain drops..lovely..

What suggestions do you have for improving the event?

Just the suggestion about using Skype or telephone, and testing the connection before the presentation.
I suggest you work more on the IT infrastructure to facilitate a better interaction with the online speakers.
Perhaps wider dissemination among DMU and its local academic and business contacts to achieve a wider local impact.

*Present sessions after opening speech *Session head introducing the session in a few sentences, then presentations, also to find unifying issues for the Q/A session
Have a conference dinner on the first night. If funding is an issue, this could be an optional paid-for add on to the conference.
(1) Wider participation from other universities (2) Charging a fee (that way people are more likely to [a] see value in the event and [b] actually show up - there were lots of unclaimed badges by the end of the first day (3) Perhaps the Head of School could show their support by giving a short welcoming address
More information to internal DMU staff beforehand
More dissemination and more involvement of students and PhD students.
It was really good
This was a great event. Congratulation for the great work.
The workshop should be launched in the in the afternoon of the first day so that in the second day there should be more time for the conclusions of the workshop. Or may be one day extra reserved for the workshop that would include a concrete case study. Architectural tour of the campus with presentation of sustainable design aspects within the campus