MMOKOLODI SOLAR PV PROJECT – DEMONSTRATING SUSTAINABLE RENEWABLE ENERGY SYSTEM DESIGN AND POTENTIAL FOR BOTSWANA RURAL ELECTRIFICATION

Cheddi Kiravu[α], Silvia Emili[β], Lapologang Magole[χ], Annah Mandu Jeffrey[α], Christian Mbekomize[α], Edward Matlotse[α], Edward Rakgati[δ], Tunde Moses Oladiran[λ], Kelebaone Tsamaatse[α], and Fabrizio Ceschin[β]
University of Botswana[α], Brunel University London[β], UB - Okavango Research Institute[χ], University of Botswana, University of Botswana, University of Botswana, BITRI[δ], Botswana International University of Science and Technology[λ]
Botswana[α χ δ λ], UK[β],
cafeecheddi@gmail.com, Silvia.Emili@brunel.ac.uk, lapologangmagole@gmail.com, jeffreym@mopipi.ub.bw, mbekomizecj@mopipi.ub.bw, matlotsee@mopipi.ub.bw, erakgati@bitri.co.bw, mostunde@gmail.com, tsamaase@mopipi.ub.bw, fabrizio.ceschin@brunel.ac.uk

ABSTRACT
The aim of this paper is to introduce the AU-funded distributed solar photovoltaic (PV) research project currently being implemented at the Mmokolodi Village in Botswana. The paper shall outline the potential of the project for rural electrification and assess system design considerations guaranteeing its sustainability. A descriptive methodology is considered sufficient to capture the complexity of the project's design goal and its sustenance beyond the project time. The inherent complexity cited underlines the need for a holistic system design view embracing technical, social, economical, environmental, and ownership dimensions. These dimensions are substantiated in the paper applying suitable frameworks. Within one of the frameworks, an overview of possible business models is explored, in particular looking at Product-Service Systems and related ownership models as promising approach for project sustainability. The current status of this ongoing research work limits definitive commentary about the expected final result. Whereas valid business case statements for sustaining the Mmokolodi project can already be made, the other sustainability metrics namely feasibility, viability and desirability remain projected goals. The results of this research exemplify the need for interdisciplinary collaboration in sustainable energy research undertakings. The assessments made will help future project implementers to anticipate implementation hurdles proactively. The results will help energy end-users at the Mmokolodi community to access affordable modern energy and assess its desirability. For policy planners these results may shape energy planning to embrace the complexity inherent in the energy planning process.

KEY WORDS
Rural Mmokolodi Botswana, sustainable PV design, complexity, ownership models, multi-dimensional, multi-scale, multi-stakeholder, participatory assessment.

1. Introduction

This paper describes the potential and sustainability of the AU-EU-funded Mmokolodi Village Grid-connected Solar Photovoltaic (PV) Project (MGPVP) in Botswana. The description relates the technical design solution to the social-technical project goals for specified MGPVP stakeholders. This assessment is proceeded by a consideration MGPVP's technical design details. This is followed by a discussion of projected MGPVP outcomes relative to stakeholders' expectations. This background will frame the sustainability narrative following thereafter.

The sustainability narrative is wrought in complexity. The emergent complex MGPVP issues compelled a cross-linkage of research results congruent upon sustainability. Consequently the notion of sustainability in this paper draws from the research goals and expected outcomes of two separately funded ACP-EU EduLink II projects namely, PARTICIPIA (**Part**icipatory **I**ntegrated **A**nalysis of energy systems)[1] - based on Giampietro's **MuSIASEM** - **Mu**lti **S**cale **I**ntegrated **A**nalysis of **S**ocietal and **E**cosystems **M**etabolism – [4] and research conducted within the auspices of **LeNSeS** (**Le**arning **N**etwork on **S**ustainable energy **S**ystems)[2] [3] [6] with the MGPVP acting as a specific application case. In particular

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[1] The PARTICIPIA project partners are University of Botswana including the Okavango Research Institute, Universidad Autonoma De Barcelona, Universidad Autonoma De Madrid, Universidad Carlos III De Madrid, Stellenbosch University, Polytechnic of Namibia, University of Bergen, FAO and NEPAD

[2] Research conducted within another Edulink II project, LeNSes

[3] The LeNSes project involves Brunel University London, Politecnico di Milano, TU Delft, Makerere University, Cape Peninsula University of Technology, University of Botswana, University of Nairobi

arguments for the sustainability of the MGPVP as a business case were derived from ownership models and options based on Emili's research. The narrative of the MGPVP's societal sustainability on the other hand is based on three key MuSIASEM concepts: Feasibility, viability, and desirability.

2. The Mmokolodi Grid-connected Solar Photovoltaic (PV) Project (MGPVP)

2.1 The MGPVP Objective

The MGPVP is part of a collaborative joint research project[4] funded by the European Union (EU) through an African Union (AU) research grant fund to design and install a total of 50kWp distributed grid-connected solar photovoltaic (PV) system in Botswana and Ghana. The MGPVP research site in Botswana is at Mmokolodi Village where a 20kWp PV system shall be installed at the Village Chief's Administrative Headquarter - The Kgotla, some Village Development Committee (VDC) quarters, at the Village's Clinic, and the Chief's residence. The key MGPVP stakeholders include the Botswana Power Corporation (BPC) - the only power utility in Botswana -, the Department of Energy - responsible for energy policy in the Ministry of Minerals, Energy \& Water Affairs -, BPC Lesedi - An arm of the BPC responsible for rural electrification -, and the Mmokolodi VDC - comprising the energy end-users. Post project commissioning considerations may enable further customers to be connected to the MGPVP.

The overall objective of the MGPVP is to demonstrate the potential of distributed grid-connected solar PV systems in rural electrification schemes for improved affordability and sustainable energy access. Towards this objective aspects of the project relevance to sustainability of the MGPVP shall be considered: solar resource available at the project site, the technicalities of implementing the MGPVP, the engineering challenges of the proposed MGPVP, the economical attractiveness of the MGPVP both to system operators and end-users, and the societal sustainability considerations from a view that informs energy planning. The outcome is expected to lead to a development of a strategy for enabling the utilisation of distributed grid-connected solar PV to meet the energy access and affordability challenges in rural Botswana

2.2 MGPVP and the Botswana's Energy Situation

The MGPVP objectives speak to the energy situation in Botswana where, compelled by a growing energy demand and an insufficient indigenous supply, the country depends on electricity import. The widespread exploitation of solar PV could supplement coal-based electricity generation and thus ameliorate energy imports while addressing environmental concerns associated with the use of coal[5]. Botswana's peak demand was 598MW in 2014 and is expected to reach 902MW by 2020 [10]. REEEP 2014 statistics indicate that Botswana supplied only 392MW equivalent to 65.5\% of its total peak demand in 2014 thus relying on electricity imports from Eskom to supply the 206MW shortfall. Energy access in Botswana standing at 58% in 2012 [10] and 66% in 2014 [19] is projected to continue growing and reach 80\% by 2016 [18], [19]. However Botswana's geographical location shown in Fig. 1 with 3200 sunshine hours on

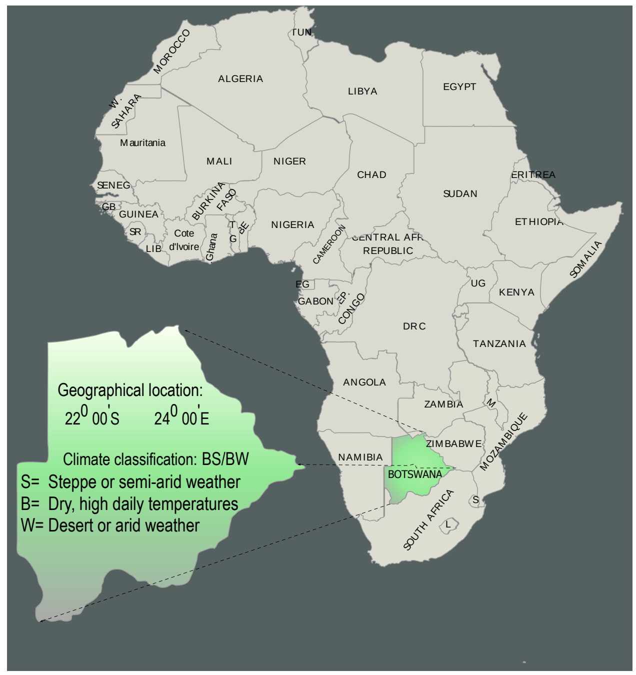

Fig. 1 Botswana's geographical location [8]

average per annum and Global Horizontal Irradiation (GHI) levels shown in fig. 2 averaging above $2.5MWhm^{-2}a^{-1}$, makes the country ideal for solar PV applications. Yet despite the huge solar resource potential the target share of electricity from renewables, projected to be 1% by 2016 [18], [19] remains insignificantly low. The potential of MGPVP must be examined against this backdrop.

2.3 Expected Project Outputs

The MGPVP is expected to demonstrate the technical feasibility of the project, provide information substantiating the operational performance of grid-tied solar PV, quantify the annual energy yield locally consumed and/or sent to the Grid, quantify end-user financial benefits, train local energy end-users, produce

[4] Involving the University of Botswana (UB), the Kwame Nkrumah University of Science & Technology (KNUST) in Kumasi Ghana, and the University of Flensburg (UF) in Germany

[5] Botswana's coal reserve is estimated at 212 Billion tons

technical manual for the design, sizing, installation, and operation of grid-tied solar PV plants and propose guidelines for policy formulation targeting distributed solar PV systems. The project shall accomplish the latter taking into account a critique of the MGPVP from a societal perspective. Finally the MGPVP shall propose a business model for sustaining end-user energy services. Most of these outputs can only be achieved after the project is completed and commissioned. In the following section we present some detail of our view of the sustainability of the MGPVP.

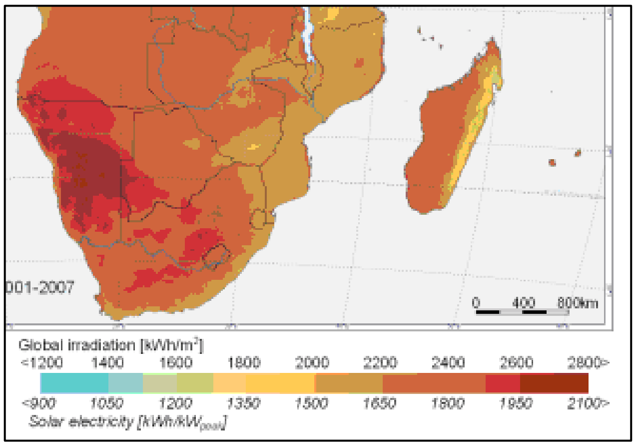

Fig. 2 Botswana's solar resource potential [11]

3.0 MGPVP Design

Generally the energy consumption in the rural areas is low during the day. Most rural electrification systems thus consist of long low-voltage lines carrying very little if any electricity during the day. People in the rural areas consider the electricity tariffs high. Access to electricity services is therefore a reserve for a few. The innovation built into the MGPVP design is intended to solve this dual problem. Firstly it is intended to empower individual energy end users to generate electricity during the day and feed any excess back to the Grid, the latter acting thereby as the storage. Secondly it proposes an ability to send back to the customer the "banked" electricity through a credit system guaranteed by policy. This innovation first obviates the need for costly battery storage that end-users hardly afford. Being equivalent to empowering energy end-users to potentially "sell" the power they generate back to the Grid, the innovation affords end-users a financial capacity to access energy at considerably lower affordable rates. Thirdly the arrangement is advantageous to BPC that is then able to operate its otherwise idle low-voltage transmission lines more efficiently.

The MGPVP was designed to demonstrate how the engineering challenges peculiar to rural grid-connected solar PV systems could be overcome. The MGPVP innovation can be realised if net metering arrangements are instituted by policy for instance within a renewable energy feed-in tariff (REFIT) law targeting solar PV. In relation to netmetering, the technical and operational experiences gained from the MGPVP would provide answers to operational challenges associated with desegregated monitoring and metering of distributed solar PV loads. The MGPVP could is potentially a useful source for useful inputs required the formulation of solar energy policy in Botswana. Other challenges include power quality concerns due to the intermittence of solar PV. This challenge is addressed by using power quality analysers to quantify and dispel power quality concerns.

3.1 MGPVP Singleline Diagrams

The MGPVP comprises of four separate subsystems namely a 2kWp at the Village Chief's residence, a 3kWp and 10kWp at the Village Kgotla, and a 5kWp at the Village Clinic. The type of technology used in the 2kWp, 5kWp, and 10kWp subsystems is polycrystalline cell technology. The 3kWp subsystem comprises of three 1kWp panels each employing the mono crystalline, polycrystalline, and amorphous thin film cell technology modules as shown in Fig. 3 as a representative singleline

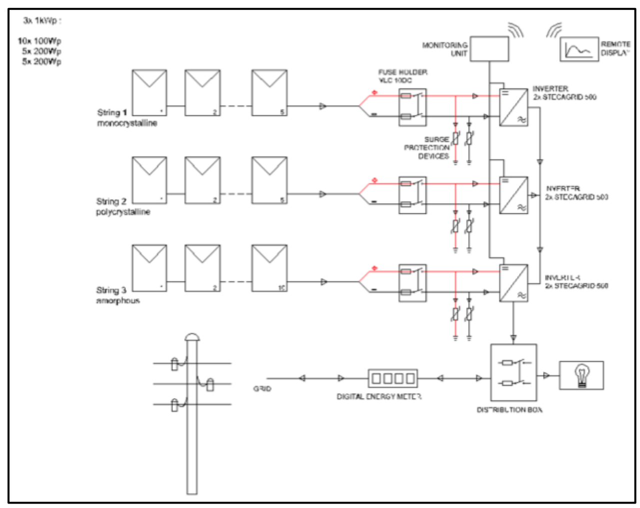

Fig. 3 The 3kWp subsystem singleline diagram

diagram for all subsystems of the MGPVP. Serving as a UB solar research station, the 3kWp subsystem shall be housed in an air-conditioned room where MGPVP data logging, condition monitoring, operation, and remote communication equipment shall be housed. The subsystem will provide comparative performance data of the three solar cell technologies under similar test conditions. The result will in turn provide a measure of the relative suitability of the three technologies for the conditions in Botswana. A pictorial view of one possible configuration for the implementation of the singleline diagram is shown in Fig. 4 from the MGPVP installers [6].

[6] Steca® catalogues provided by Communications and Accessories GmbH, CAA®

3.2 Salient Features of the MGPVP Subsystems

Besides the solar modules used in the MGPVP, important Balance of System (BOS) and interrelation with other equipment tied to this research are shown in fig. 4. These include grid-tied inverters; grounding, lightning protection, and surge protection equipment; smart energy management meters; data logging, metering, monitoring, and communication equipment; automatic weather system; and power quality analyser components. The smart energy management meter ALE3 with in-built capability for individual invoicing of shared systems shall be used to demonstrate the management of separate loads feeding from a MGPVP subsystem. An exhaustive list of the BOS, not included here, would be needed while undertaking a life cycle analysis of the MGPVP.

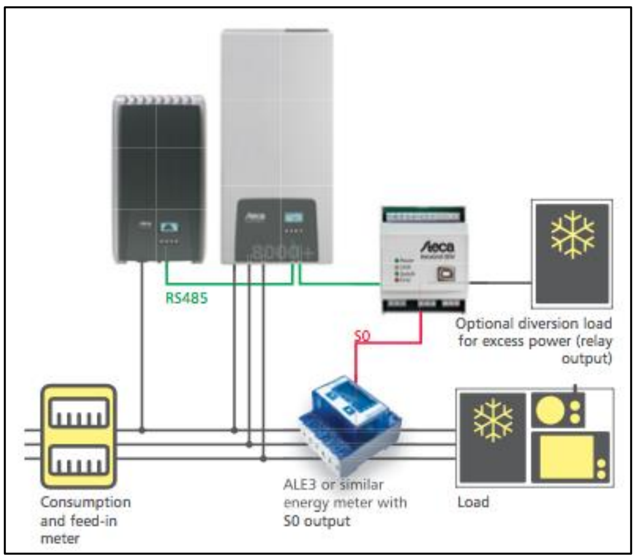

Fig. 4 System module-BOS configuration

For the system shown in fig. 4, data logging, monitoring, communication and visualization occurs intelligently. A brief explanation follows in the next subsection.

3.2.1. Data logging, monitoring, communication, and visualisation

The Global Horizontal Irradiation (GHI) and the Direct Normal Irradiation (DNI) parameters of the incident solar resource are measured using a pyranometer and pyrheliometer respectively mounted as part of an automatic weather station. The values of the parameters are remotely communicated to a state-of-the art central data logging, monitoring, visualisation, and communication system. There, the data is integrated with plant monitoring data to give an instantaneous account of the status and performance of the MGPVP. Researchers may analyse such data at a convenient remote station. It is envisaged that such data will be available in real time on the UB internet webpage. The illustration in Fig. 5 shows the interconnection of Steca-based inverter and data logging, monitoring, visualisation, and communication equipment.

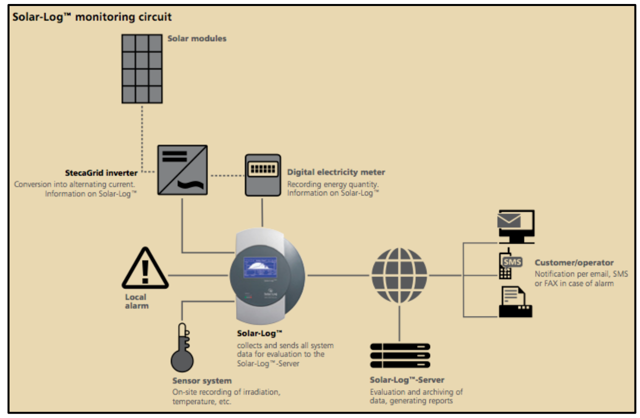

Fig. 5 Data logging, monitoring and communication

3.2.2. Management of Power Quality Issues

Part of the objective of the MGPVP is to demonstrate the potential of managing power quality issues. In the MGPVP, power quality analysers from PowerSight® shall be employed. The series of experiments conducted shall assess power harmonics during lightning or simulated lightning conditions

3.3 Management of Power Quality Issues

The implementation of a funded research project is a complex management process not least due to the diversity and necessary coordination of stakeholders. Our experience warns of unexpected delays due to third party go-betweens. Anticipated fund transfers may be delayed by local banking regulations governing foreign currency transactions. Local procurement regulations may also impose local implementation delays. Whereas project timelines are critical to researchers, third parties may not see the urgency. One possibility is to re-negotiate the project start so that the countdown for project execution coincides with the date funds are actually deposited at the local bank. Notwithstanding this, we are able to address these expectations using the following subcategories of sustainability.

4. MGPVP Sustainability

We discuss the potential of the MGPVP by providing answers to the question whether or not the MGPVP is sustainable based on Bruntland's definition of sustainable development [14], [7]: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Alternatively, "a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations". In this case, *development/process* of change refers to energy development providing energy services through distributed grid-connected solar PV systems and *needs or aspirations* refer to the ability/potential for sustaining stakeholders' aspirations relative to those services.

As researchers UB's stake in the MGPVP is to showcase the appropriateness of using solar PV for energy services provision to end-users in rural communities. The aspirations of the end-users on the other hand are to access and afford modern energy services. Their aspirations may only be guaranteed if the expectations of the utility company, the BPC, are fulfilled. The BPC on the other hand expects to see demonstrable evidence of a technically sound and operationally safe grid-integrated MGPVP. If the MGPVP compromises the integrity of the BPC network or the quality of the current BPC energy services, BPC would not grant access to its network. In contrast, the experiences gained from operating the MGPVP may prove useful to the Department of Energy particularly in relation to energy planning. Finally for Botswana, the impact that a widespread use of solar PV has on the National energy demand is important. We address these expectations using the following subcategories of sustainability

4.1 Technological Sustainability

Solar technology is a proven technology. Globally its installed capacity grew from 100GWp in 2013 to 177 GWp in 2014 [19]. In Botswana though, the MGPVP is the first and the only grid-connected solar PV system at the 400-V distribution network[7]. The sustainability of the MGPVP depends on the extent to which the new energy and water regulatory authority provides guarantees for grid access by distributed solar PV plants.

4.2 Sustainability of the MGPVP Innovation

Closely tied to the technological sustainability of general solar PV installations in Botswana is the sustainability of the technical innovation that the MGPVP represents. As mentioned in section 3, the innovation relies on the ability of individual end-users to generate own solar energy and to feed any excess to the BPC Grid. This innovation works only if it is guaranteed by policy, that the units of electricity an end-user "feeds" to the Grid can be credited back to him/her through a netmetering scheme. A renewable energy Feed-In Tariff (REFIT) law is currently under consideration in Botswana. Should Botswana's REFIT provide for a net metering clause, the innovation inherent in the MGPVP can be sustained.

4.3 Societal Sustainability

We next elaborate on the sustainability of the MGPVP from the point of view of the society based on the interpretation of sustainable development as defined at the beginning of this section. We first advance arguments why society sustainability is complex process. An organised social entity in society - be it at the household, village, regional or the highest national level - requires the expenditure of energy to sustain the societal functions. The societal functions guarantee the entity's survival and reproduction. A society expending energy, materials and other resources to maintain, reproduce and improve its own existing structures and functions is by definition [5] a metabolic system whose metabolic pattern can be likened to that of a biological living organism. Energy metabolism is attended to by energy losses, environmental emissions and re-direction of some of the generated energy carriers for the production of more energy carriers. The process of energy resource extraction, processing, transformation, transmission, and eventual consumption in the various societal compartments (sectors and sub sectors) is therefore complex. The complexity derives from among others the nonlinear resource flows and the inextricable linkages indicated in fig. 6 between societal energy, water, and food land land-use.

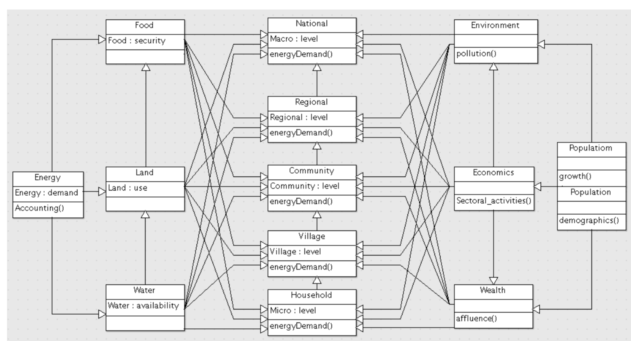

Fig. 6 Inextricable linkages in the energy, water, land-use and food nexus

As a consequence of this nexus, any analysis of one of these dimensions cannot ignore a consideration of the other three. Societal sustainability must therefore account for the existence of multiple dimensions in the analysis. Additionally for any one of the multi-dimensions, the resources accounting occurs at different scales. These scales represent the different levels at which the organisation of society could be viewed. One view could be to consider resource accounting at the dissipative sectors of the society namely the Household, and Service & Government sector levels. An alternative view could involve the consideration of the Household, Community, Village, Regional, or National level. Another characteristic of energy metabolism is nonlinearity of

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[7] The Phakalane 1.3 MWp solar PV connects to the Grid at the 11kV transmission voltage level

resource flows. This is caused by the utilisation of part of the generated energy carriers for generating energy carriers as shown by the autocatalytic energy loop in fig. 7.

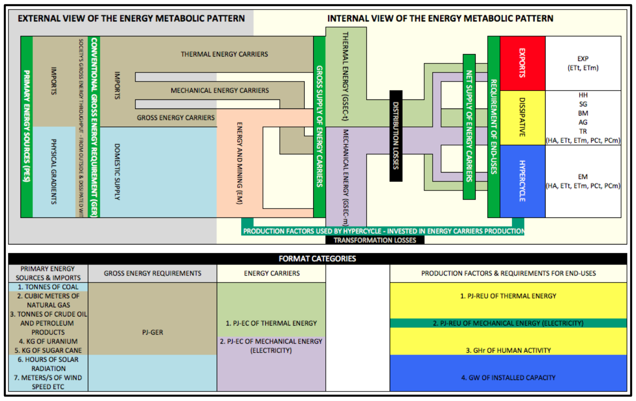

Fig. 7 External and internal views of a metabolic process in MuSIASEM (Adapted from [5])

Nonlinearity implies that the traditional linear output-input relations do not hold. Societal sustainability is therefore a complex multi-dimensional, multi-scale non-linear problem. Such a problem can only be analysed by a framework integrating all the pertinent characteristics of societal metabolism. **Mu**lti **S**cale **I**ntegrated **A**nalysis of **S**ocietal and **E**cosystems **M**etabolism (**MuSIASEM**) is the only such a framework [1], [4], [2]. It is a framework for integrating non-equivalent quantitative data for the diagnostic analysis and simulation of alternative scenarios of a societal energy metabolic pattern. The objective is thereby to assess the sustainability of the metabolic pattern in terms of its feasibility, viability and desirability. The theoretical underpinning of MuSIASEM draws from complexity theory, biophysical economics, and impredicativity theory. These theoretical frameworks warrant dedicated separate research and documentation[8] beyond the scope of this paper. We only present here an introduction to MuSIASEM as it applies to considerations related to MGPVP's societal sustainability.

The MuSIASEM framework can be used as diagnostic or as a simulation tool. As a diagnostic tool it establishes the current metabolic pattern of a given society in relation to a particular resource. As a simulation tool, it is used to analyse the alternative scenario of metabolic pattern for its feasibility, viability, and desirability. In the MGPVP MuSIASEM is first used to analyse the resources availability and their pattern of use in the village to establish a baseline metabolic pattern. Thereafter the framework shall be used to simulate the alternative metabolic pattern as a result of introducing solar PV. To operationalize a MuSIASEM framework, the societal system being analysed is first suitably defined as a hierarchical structural organisation, for instance that shown in fig.8

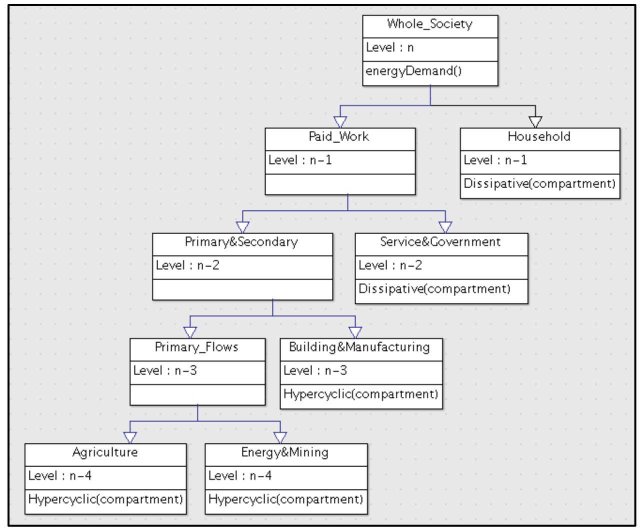

Fig. 8 Hierarchical functional organization of society

The definition must be such as to ensure that the system compartments reproduce the societal functions. The starting point applying MuSIASEM is thereby the society's total population based on the premise that the population accomplishes the functions of the entire society. These functions, carried out on a yearly basis, subdivide the total human activity (THA) - measured in hours of the population given that 8760 hours are available per individual per year - into the Household and PaidWork sub-sectors. A further successive subdivision of the PaidWork sub-sector is carried out resulting in the depicted hierarchical structure.

The process of generating a net supply of energy carriers (EC) in MuSIASEM is conceptualised as indicated in fig. 7 where resource flows and funds defined in biophysical economic terms [6] are analysed within a dual view of the metabolic pattern in order to assess the dominant features constraining the pattern [2]:

- The external view, in which primary energy sources provide inputs to the metabolic process. The inputs are constrained only by the biophysical realities on the supply side and the existence of sufficient capacity to absorb the generated environmental waste on the sink side. As these are not subject to human control they define the external constraints to the metabolic process. The external view assesses sustainability in terms of the external constraints questing the feasibility of the metabolic process given the constraints. The feasibility of the MGPVP shall assess the availability of sufficient EC and the existence of sink capacity to stabilise the metabolic pattern.

[8] Doctoral research - UB Faculty of Engineering \& Technology

- The internal view, within which fund elements are invested to ensure the realisation of a net supply of EC. The ability and the extent of provision of the necessary and sufficient production factors are limited only by characteristics internal to the society. Such a view thus provides an internal perspective of assessing the metabolic pattern, questioning whether it is viable to fund the pattern given the internal societal constraints. The viability of the MGPVP shall assess the availability and sufficiency of fund elements to stabilise the metabolic pattern.

The desirability of the MGPVP will be examined after introducing the operational aspects of MuSIASEM.

4.3.1 How MuSIASEM works

Generally a MuSIASEM analysis is preceded by a definition of profiles of fund investments and flow investments across the functional sectors/subsectors (scales) defined in fig. 8. These allocation profiles are captured using bifurcation coefficients such as α, β, γ, δ indicated in fig. 9 generated using dedicated "grammars" one each for the energy, water, food, and land-use dimensions.

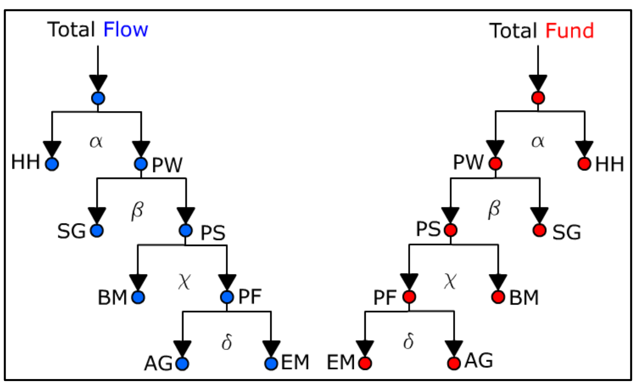

Fig. 9 Bifurcation of Flow and Fund elements (Adapted from [5])

The only requirement for the possible bifurcations is closure: Sum of the fund (flow) coefficients at a bifurcation must equal the total fund (flow) allocated at the bifurcation point. For each of the dimensions energy, water, food and land-use, the MuSIASEM methodology integrates separate fund and flow coefficients into an augmented vector of fund-flow coefficients across the functional sectors/subsectors. The resulting matrix allows for consistent checks for feasibility, viability and desirability across scales and dimensions. The matrix juxtaposing the fund and flow data coefficients across scales allows the calculation of flow-to-fund ratios.

4.3.2 MGPVP Desirability

The flow/fund ratios are significant, allowing the following deductions:

- They are intensive variables independent of size or volume of society. They can therefore assess the performance of a metabolic pattern at a particular scale by checking for the congruence of prevailing constraints using "Sudoku"-type conformity checks and comparisons with reference values for known types of socio-economic systems [5]. They then provide a means of scaling-up or scaling-down a complex metabolic assessment.
- The relative allocation and comparison of fund ratios at the different scales provide a means for assessing the size of funds invested at a particular scale. When compared against known values for specific types economies, this information is useful in classifying the emergent socio-economic system.
- The desirability of the MGPVP shall be assessed with particular reference to the MGPVP end-users after data is collected and integrated in matrix form as described above. Then the proportion of fund and flow elements invested for the dissipative sectors of society notably the household, service & government and transportation sectors, compared to available investment of these production factors at the National level shall be evaluated in a top-down assessment. The higher this relative share of investment is, the higher the standard of living at the in society. By implication therefore the higher the desirability of the metabolic pattern to household level end-users. In MuSIASEM, the extent and willingness of a society to express a higher desirability through a proportionately higher relative share of investments in its dissipative sectors subjects the society to a bioeconomic pressure (BEP). The assessment of the BEP underscores the use of impredicativity theory in MuSIASEM. Impredicativity arises from the fact that an emergent macro-level result (e.g. the result of energy metabolism at the national level) constrains a bottom-up phenomenon from which the result derives. This chicken-and-egg dilemma can be illustrated in the MGPVP

A participatory assessment - a kind of a bottom-up assessment - of Mmokolodi village was carried out to generate data for the energy metabolism in the village. In it stakeholders "paint" pertinent narratives of the energy characteristics obtaining in their village as shown in fig. Fig. 10 where the exercise was to demarcate the boundaries of the village map.

Fig. 10 Participatory mapping of Mmokolodi village

The map shown in fig. 11 was generated using this process. It will be used to generate MuSIASEM GIS data for land-uses at Mmokolodi.

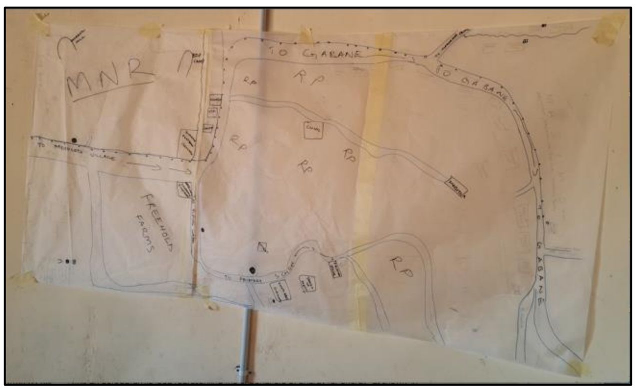

Fig. 11 Mmokolodi map for MuSIASEM GIS data

4.4 Sustainability of the MGPVP Business Case

Grant research projects may fail if the beneficiaries are not provided with a business case guaranteeing their eventual sustainability. We explored the complex issues related to project design for sustaining distributed solar PV in the rural areas. We subjected the MGPVP as a test case to the choices open for its sustainability. In the following section we present the issues, models, and global best practices against which the sustainability of the MGPVP business case could be inferred.

Considering the previously mentioned challenges in terms of technology, policy support, variety of stakeholders involved and economical sustainability, it is clear that several factors need to be simultaneously considered for the successful implementation of the MGPVP. For these reasons, it is important to consider the project from a systemic dimension. In fact the successful implementation of complex solutions such as the MGPVP is not only a technical matter. It is also, and especially, a matter of designing appropriate business models and product-service propositions. This means that multiple elements, such as technology, services offered, stakeholders' roles, payment structure and target customers, must be taken into consideration at the same time.
Within this premise, the model of Product-Service System (PSS) appears to be promising to be applied to Distributed Renewable Energy systems [16]. PSSs can be defined as value propositions where "a mix of tangible products and intangible services are designed and combined so that they are jointly capable of fulfilling final customer needs" [13].

4.4.1 PSSs Categories

PSSs can be classified into three main value categories [15], [12]:

- Product-oriented PSS - where a company provides additional services such as maintenance, repair, and take-back to guarantee life cycle performance of the product sold to the customer.
- Use-oriented PSS – A values proposition where a company offers access to products, tools, opportunities or capabilities that enable customers to get the results they aim to. The client obtains the desired utility but does not own the product and pays only for the time the product is actually used.
- Result-oriented PSS - value offers where a company provides a customised mix of services, as a substitute for the purchase and use of products, in order to provide a specific 'final result'. This in other words, represents an integrated solution to meet the customer's satisfaction. The client does not own the products and does not operate on them but pays the company to provide the agreed results.

Several benefits can be associated to PSSs. From the environmental point of view, PSSs can potentially decouple profit from resources consumption. This is because producers and providers, paid not per unit of product sold but per unit of function delivered, are economically interested in reducing the amount of resources needed to deliver that function [17], [15]. PSSs can also provide a range of economic and competitive benefits for the actors involved in the offer for example companies can find new strategic market opportunities and increase their competitiveness [15], [9]. In addition, in relation to the social dimension of sustainability, since PSS offers do not require payment for the full value of the equipment, they can enable low-income consumers to get access to solutions without the need of sustaining initial high costs [13], [15].
The previously mentioned LeNSes project is currently exploring the application of PSS business models to Distributed Renewable Energy systems (DRE) in low-income contexts. Within with this project, Emili's research is focusing on developing design approaches and tools to support companies and practitioners in designing

appropriate and sustainable business models. Some intermediate results of this research include:

- PSS+DRE Innovation Map tool [3] shown in fig. 12: The PSS+DRE Innovation Map tool provides an overview of the possible models of PSS applied to DRE and can be used to facilitate discussion about existing offers and competitors, current portfolio of offerings, new potential market opportunities and possible innovations in the selected context.

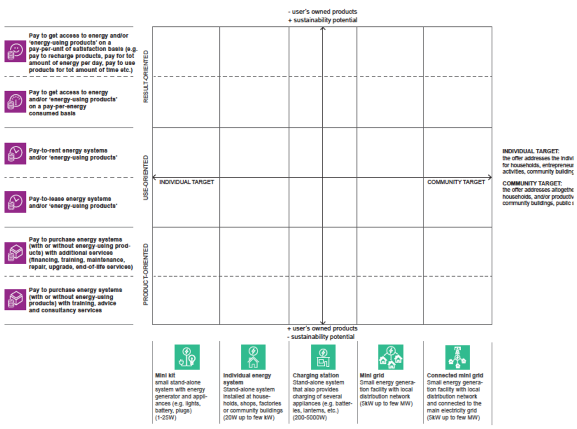

Fig. 12 PSS+DRE Innovation Map Tool

- PSS+DRE Design Framework and Guidelines (Fig. 13)

Fig. 13 PSS+DRE Design Framework and Guidelines

- The PSS+DRE Design Framework and Guidelines supports the design process by visualising and describing all the elements that to be considered in the system: network of actors and providers and their roles; technology, energy-using products and services offered; type of PSS/value proposition; payment structure; target customers and payment modality. For each of these elements, a set of cards with guidelines and case studies can provide support to the process of generating ideas.

These tools have been used in a workshop held at University of Botswana in May 2015, where some of the key stakeholders of the project discussed potential business model propositions to support the implementation of MGPVP. The workshop was structured in two main parts. The first phase aimed at exploring the possible business models that could be applied to the Mmokolodi project. Using the PSS+DRE Innovation Map, and a set of case studies, options have been explored, analysed and discussed. Two models emerged as particularly promising as shown in fig. 14

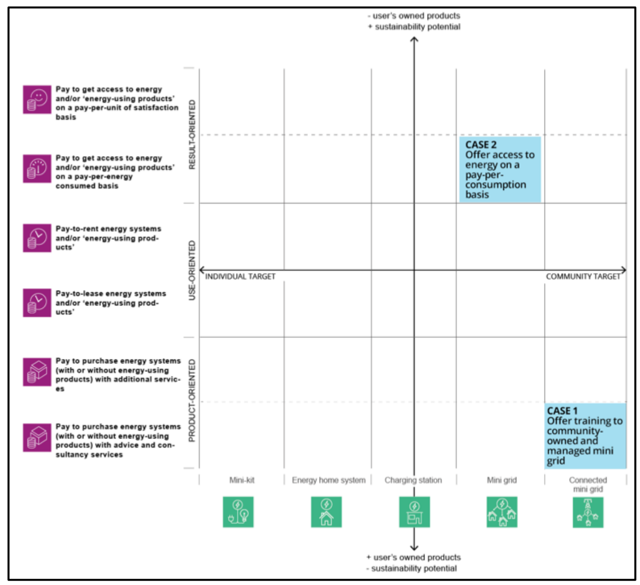

Fig. 14 Case study mapped onto the Innovation Map and used as an inspiration

- A community-owned system, where the community receives training from the technology provider and then takes responsibilities for operation and management of the PV system. The community participates in establishing tariffs and payment modalities, and sells the extra-generated electricity to the national grid supplier.
- The second suitable model is based on offering energy services on a pay-per-consumption basis, where the ownership of PV system is kept by the providers (BPC and other actors) and customers get connected to the mini grid and pay proportional to the kWh consumed

In the second phase, the aim was to detail the generic models previously identified. To this end the PSS+DRE Design Framework and Guidelines was used to stimulate idea generation on the different elements of a business model in fig. 15. Particular attention was devoted to defining the key possible roles of the main stakeholders of the project:

- The VDC: provides basic maintenance, for instance cleaning of solar panels, manages the plant security issues, and organises the collection of individual payments set aside for a plant maintenance fund through the VDC secretary.

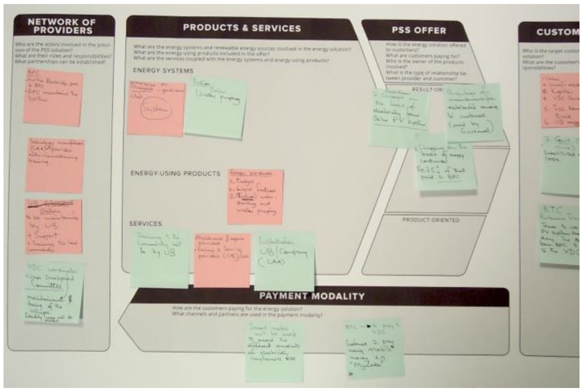

Fig. 15 Design Framework used for generating ideas in the workshop

- UB: provides training to VDC, support and maintains a research station in the vicinity of the PV station.
- BPC: provides maintenance and repair services to the solar PV plant.
- CAA: As technology installers, provides installation and initial training to UB before plant commissioning.

A critical aspect that ensures economic sustainability of the system and that will need further consideration is the payment structure. Among the proposals, two main schemes have been outlined: a consumption-based tariff integrated with the use of smart meters, or perhaps a tariff charge to customers proportional to the difference between consumed units and units previously fed to the Grid.
Drawing conclusions from the workshop, we can say that a systemic approach is needed to tackle the multiple challenges of the project and that a PSS design approach seems promising for ensuring the long-term sustainability of the MGPVP. The PSS+DRE tools used for generating ideas and exploring opportunities highlighted options and requirements, and helped to define initial business model proposals for further future exploration and development.

5. Conclusions

This paper introduced the MGPVP using detailed descriptions of frameworks necessary to comprehensively assess its sustainability. Latter involved: Technological sustainability - to assess the existence and sufficiency of a solar resource potential at Mmokolodi, Technical sustainability - to assess the engineering challenges of solar PV integration into the Grid, Political sustainability - to assess the policy imperatives for enabling the MGPVP innovation, Economical sustainability - to assess a sustainable business case for the MGPVP at the end-user level, and Societal sustainability - made up of the feasibility, viability, and desirability of the MGPVP to assess sustainability of the MGPVP relative to external, internal, and bioeconomic pressure constraining respectively the energy metabolic pattern at Mmokolodi. Two MGPVP business models for sustaining the MGPVP were identified. However no conclusive societal sustainability projections can be made as yet. They remain subjects for an ongoing research.

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APPENDIX: Figures 6, 7, 12, 13, 15 and 14 Enlarged

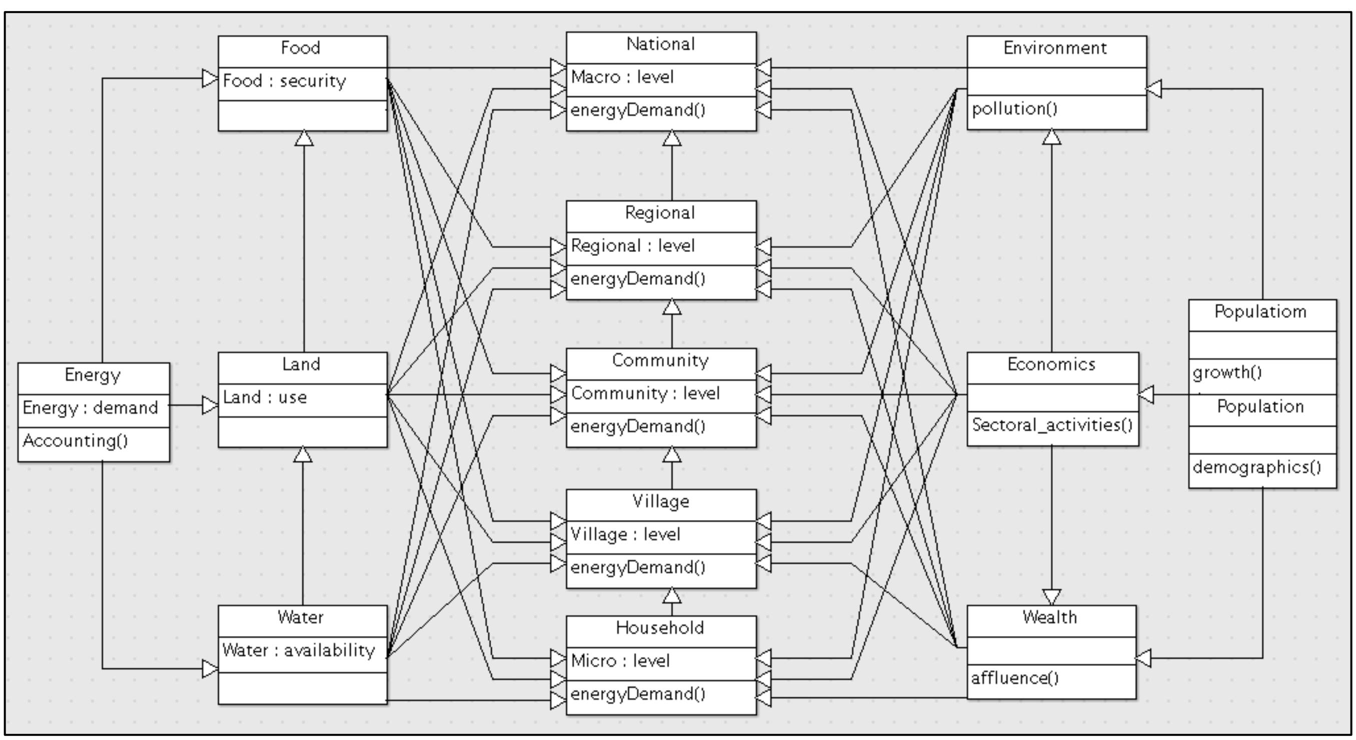

Fig. 6 Inextricable linkages in the energy, water, land-use and food nexus

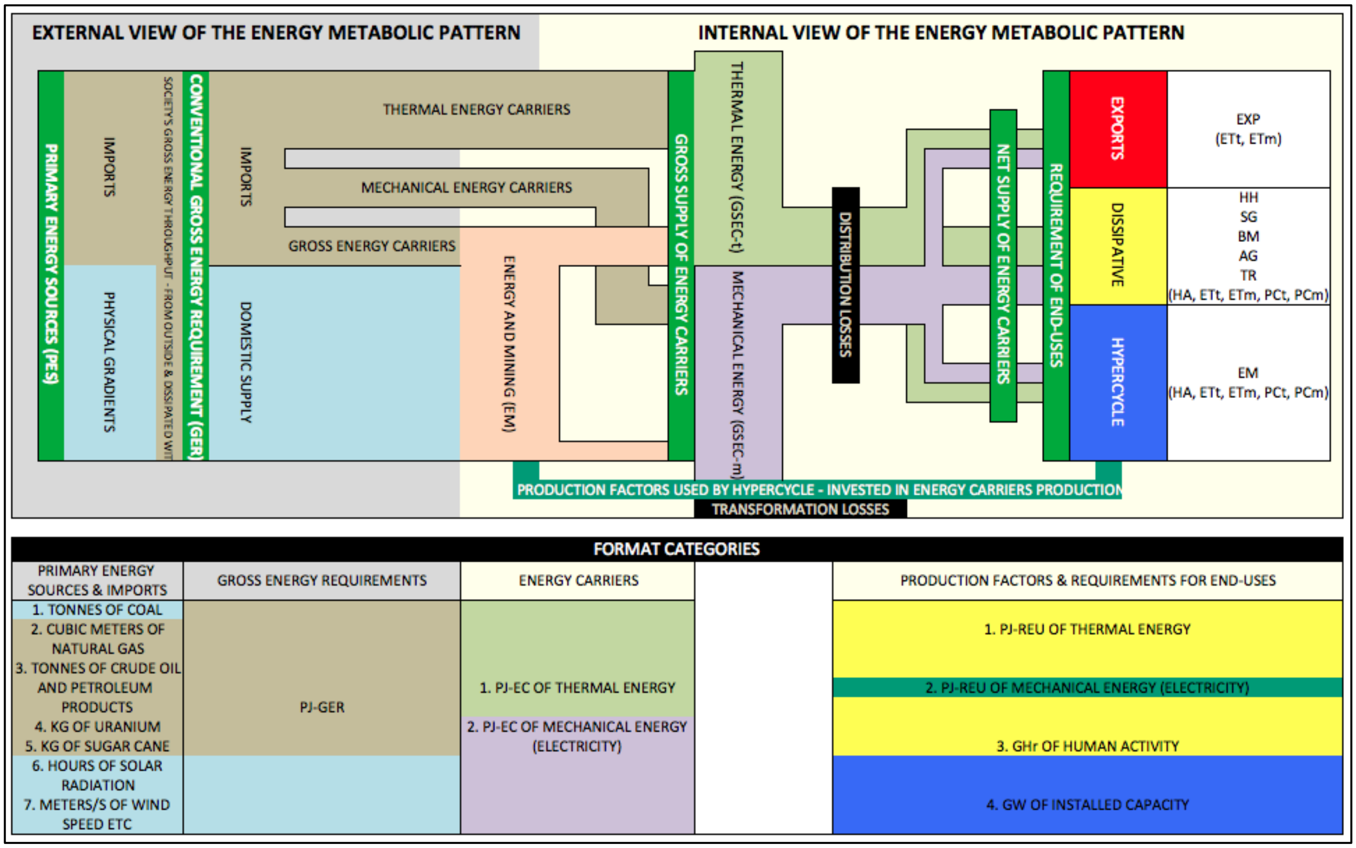

Fig. 7 External and internal views of a metabolic process in MuSIASEM (Adapted from [5])

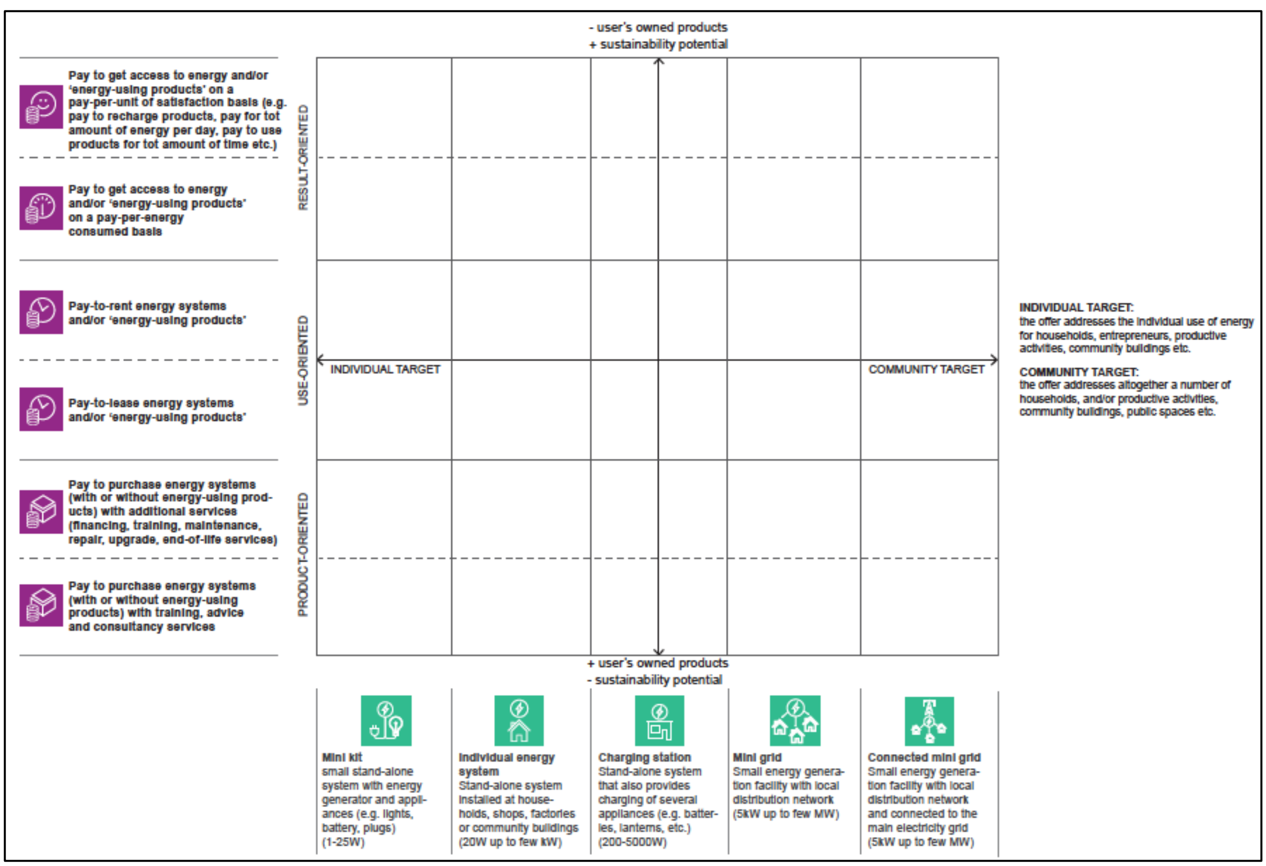

Fig. 12 PSS+DRE Innovation Map Tool

Fig. 13 PSS+DRE Design Framework and Guidelines

Fig. 15 Design Framework used for generating ideas in the workshop

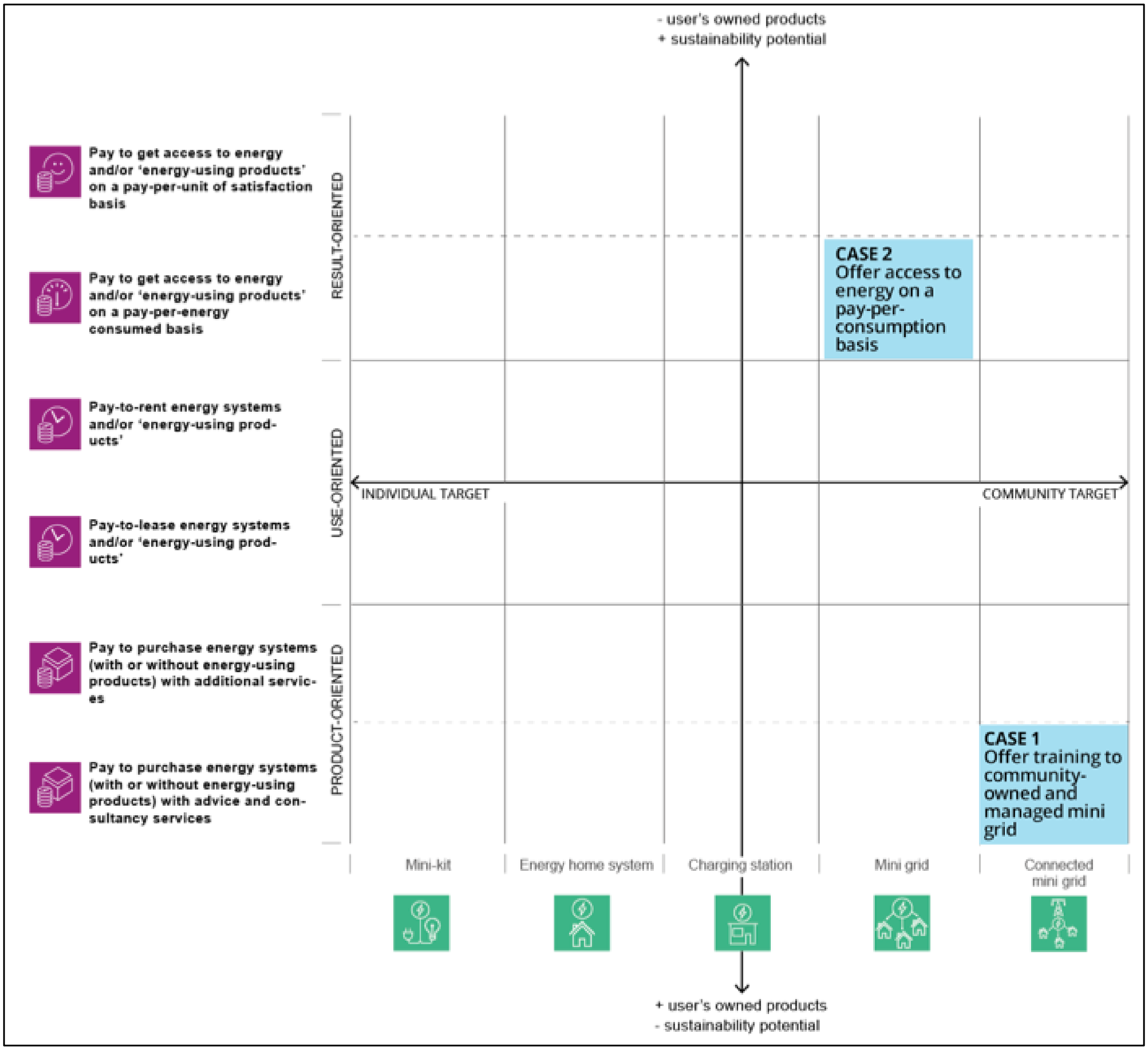

Fig. 14 Case study mapped onto the Innovation Map and used as an inspiration