Visualising Product-Service Systems applied to Distributed Renewable Energy: the Energy System Map

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Abstract

Energy access in Bottom of the Pyramid contexts represents a serious hindrance to sustainable development for about 1.4 billion people living without modern energy services. Distributed Renewable Energy (DRE) systems are considered a feasible approach to provide locally-produced, reliable and sustainable energy in rural areas and informal settlements but these models require appropriate business models to be successfully implemented. This research investigates the applications of Product-Service Systems (PSS) to DRE systems and argue that these types of value propositions can successfully provide energy solutions in low-income contexts. In particular, the aim of this research is to provide strategic tools for supporting companies and practitioners in the design process of PSS applied to DRE. In this paper we introduce a tool for visualising and designing these solutions: the Energy System Map. Drawing from the system map tool (Jegou et al. 2002) and adapting it to the specific context of DRE and energy access, we illustrate how the Energy System Map has been applied in the design process with companies and practitioners from Kenya.

Key Words: Product-Service Systems, Distributed Renewable Energy, design tool, system map

1. Introduction

This research addresses the problem of energy access for 1.4 billion people living in low-income and developing countries. The lack of modern energy services, particularly critical in rural areas and informal urban settlements, represents a serious hindrance to sustainable development (UN 2014) and the link between human development and energy access has been highlighted in several studies.

Bottom of the Pyramid (BoP) customers usually lack access to capital, have low energy demand (Zerriffi 2011) and spend a considerable portion of their income for providing basic energy services using polluting and dangerous fuels (IFC and WRI, 2007). Several studies (Zerriffi, 2011; Myers, 2013; OECD/IEA 2010) argue that the grid extension is not going to reach those customers in the short-medium term but that Distributed Generation will represent 70% of energy generation by 2030.

Distributed Generation is defined as *"electric power generation within distribution network or on the customer's side of the network"* (Ackerman et al. 2001) and appears as a promising approach to provide energy solutions in Bottom of the Pyramid contexts (Zerriffi, 2011). When renewable energy sources are implied, we refer to **Distributed Renewable Energy (DRE)** systems, which represent sustainable solutions for allowing communities self-sufficiency, resulting in lower transmission costs for dispersed areas, greater flexibility and economic resilience (Friebe et al. 2013; Terrado et al. 2008; Zerriffi 2011).

DRE models are not always easy to be implemented. Despite the technical constraints such as limited capacity, low voltage and transmission, the implementation of DRE system requires pertinent policies (Beck and Martinot 2004; Terrado et al. 2008) and suitable business models that consider local service provision, affordability for lower-income customers and access to capital financing (Schäfer et al. 2011; Terrado et al. 2008).

For these reasons it is promising to look at **Product-Service System (PSS)** as appropriate business models for delivering energy access in BoP contexts. PSSs have been defined as *"a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs"* (Tukker and Tischner 2006) and imply a shift from a traditional ownership-based model to offering a satisfaction-based solution (e.g. from selling lighting systems to providing an agreed amount of lux).

Among their several benefits, PSSs present higher sustainability potential compared to traditional business models. PSSs can decouple economic value from consumption of materials and energy (White et al., 1999; Stahel, 2000; Heiskanen and Jalas, 2000; Wong, 2001; Zaring et al. 2001; UNEP, 2002), meaning that profits are linked to unit of performance instead of unit of product sold, hence providers are economically motivated to reduce energy and material resources.

The applications of Product-Service Systems in BoP contexts have been explored by several authors (Castillo et al. 2012; Jagtap and Larsson, 2013; Shafer et al., 2011; Moe and Boks, 2010) and their benefits include higher access for low income customers (Tukker et al. 2006), influence on socio and economic development due to overcoming the stages of individual consumption and ownership (Tukker and Tischner, 2004), potential to tackle critical BoP issues such as resource use and waste (Schafer et al., 2011).

In conclusion, combining PSSs and DRE models seems relevant to tackle the issue of energy access in developing and BoP contexts. Several advantages can in fact emerge from these models (Vezzoli et al., 2015): from an environmental point of view they present reduced environmental impact, increased reliability and efficiency. In terms of economic advantages, the combination of PSS and DRE results in lower costs of transmission, reduced investment costs and flexibility. From a socio-ethical perspective, these models allow increased energy independence, increase of employment and consolidation of local economies, customisation to users' needs.

The overall aim of this research is to explore the applications of PSS and DRE in BoP contexts and to provide strategic design tools that support the design process of these solutions. Previous research work resulted in presenting a classification system for PSS and DRE models (Emili et al., 2016(a)), design tools for mapping PSS+DRE, exploring new opportunities and generating business concepts and supporting the design of PSS applied to DRE (Emili et al., 2016(b)). What emerged from our previous work is the need for an appropriate visualisation system that can be used by companies and practitioners to design and communicate these types of energy solutions.

A variety of methodologies and tools exist for PSS design visualisation (Ceschin et al. 2014) and they can be applied in different phases of the design process. In particular, the elaboration of a visualisation system is considered a necessary support for the definition and development of stakeholders networks (Krucken and Meroni 2006). However, in relation to DRE models, PSS tools lack a specific focus on energy access in low-income contexts and there is a need for tailored visualisation tools that can support the designing of these particular models.

In this paper we present contribution that aims at supporting the designing process of these types of business models: the Energy System Map. First we provide a background introduction on the system map tool; then we explain the methodology used in this research and introduce how the Energy System Map has been developed. After that we describe the testing activities and we conclude with considerations for improvements and next research activities.

2. The system map

The system map, originally developed by Francois Jégou in the HiCS research project Highly Customerised Solutions, Solution-oriented design, production and delivery systems (European Research, GROWTH Programme - Jegou et al., 2004), is a tool to support the design and visualisation of a system or a Product-Service System.
It shows a graphic representation of the stakeholders involved in the system and the interactions between them, i.e. the flows of goods, services, information and money. The tool can be described as a 'technical drawing' of a system because it consists of a fixed format, a set of graphic elements (icons, arrows) and specific rules for visualisation.
This tool can be used in different phases of the design process. In the designing or co-designing phase of a system it facilitates the clarification of actors' roles and relationships, it supports the detailing phase of a concept by identifying main and secondary stakeholders. The system map can be also used for communicating the designed solution because it provides a codified visualisation (Vezzoli et al., 2015).
As argued by Ceschin et al. (2014), PSS solutions are complex models that require specific visualisation tools that support an effective communication between all actors involved and that facilitate the design and development of PSS models.
As discussed in the introduction, specific visualisation tools for designing PSS applied to DRE are missing. The system map is a versatile tool that can be used in different scenarios, however it must be revised and adapted accordingly in order to best describe the complexity of PSS and DRE models.

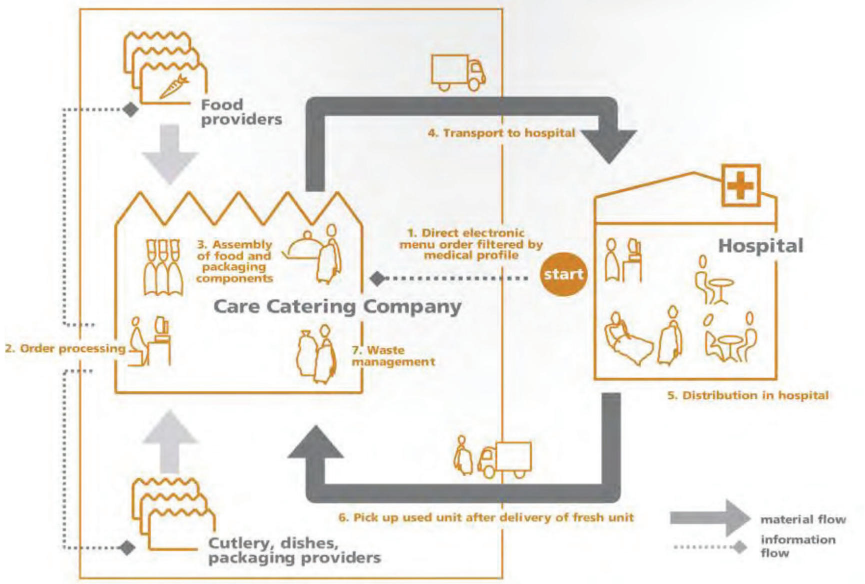

Figure 9 - Food Delivery Solutions system map. Manzini et al. 2004

3. Methodology

The methodology adopted in this research can be summarised in the following points:
1. Development of the Energy System Map. Drawing from literature review on PSS visualisation tools and from previous research activities, the icons, flows and set of rules to visualise PSS+DRE were developed.
2. Evaluation. The testing of the tool in use has been carried out during a course about designing sustainable business models for energy access in low-income contexts organised by Brunel University London and the University of Nairobi in April 2016. The four-days long course was part of the LeNSes project and engaged ten participants from local companies and consultancies involved in the renewable energy sector. Participants worked in groups and they developed a new business concept of PSS applied to DRE. Once the business model was developed (see Emili et al., 2016 (c)), participants applied the Energy System Map tool for detailing and visualising their concepts. At the end of the course they were asked to present their new business concept to the class and feedbacks were collected through questionnaires.
3. Considerations for improvements. The testing activities led to design considerations for improving the tool and its applications.

4. Development of the Energy System Map

The first step was to identify elements describing PSS and DRE models. This process was based on previous research work that identified dimensions describing PSS applied to DRE (Emili et al., 2016 (a)) and their relative variables (Emili et al., 2016 (c)). These variables can be listed as:

- *Network of providers*. It refers to the actors involved in providing the energy solutions and it includes private enterprise, technology manufacturer, community, local entrepreneur, Non-Governmental Organisation (NGO), Cooperative, Micro-Finance Institution (MFI), public and governmental entity, national grid supplier.
- *Products and services*. It refers to the combination of products (energy systems and energy-using products) and services offered. Energy systems include stand-alone systems (mini kit, individual energy system, charging station) and grid-based systems (isolated and connected mini-grid). In this section are also included the types of renewable energy sources used for DRE: solar, hydropower, biomass, wind or hybrid sources (i.e. combination of different renewables). In the product category are listed the appliances that can be included in the offer in combination with the energy systems (i.e. generator). This includes: lantern, lights and bulbs, battery, phone charger, radio, TV, fan, IT and computer devices.
  The service category includes consultancy services (training, financing) and services provided during or at the end of the product life-cycle (installation, maintenance and repair, product upgrade, end-of-life services).
  For both energy-using products and services an icon indicating "other" appears on the Design Framework. This indicates that other products or service may be added in the PSS idea generation.
- *Offer*. This element refers to the different types of PSS offer that can be applied to DRE models. Their classification is divided into: product-oriented (pay-to-purchase with training, advice and consultancy services; pay-to-purchase with additional services), use-oriented (pay-to-lease; pay-to-rent/share/pool), and result-oriented PSSs (pay-per-energy consumed; pay-per-unit of satisfaction).
- *Customer*. It refers to the type of target customers addressed in the PSS solution and includes: individual household, productive activity, local entrepreneur, public buildings, community, public and governmental entity, mix of target customers.
- *Payment channels*. This element refers to the different ways customers pay for the energy solution. It includes: cash, credit, mobile payments, scratch cards and energy credit codes, in-kind contribution, fee collection and meter reading as an activity supporting payment.

Each of those design elements has been represented with an icon that is characterised by colour-coding and a "slogan" describing the actor, product or activity (Fig. 2).

Figure 10 - Icons describing elements of PSS+DRE offers

The Energy System Map has been firstly applied for describing archetypal models of PSS applied to DRE (Emili et al., 2016(a)) in order to simplify the understanding of type of offer, products and services included, ownership, actors involved. For these reasons, the map follows some specific visualisation rules that aim at standardising each PSS+DRE model:

- The energy solution provider, which can include one actor or a partnership of actors, is represented on the left hand side of the map and it is characterised by a purple colour.
- The customer is always placed on the right-hand side of the map and it is characterised by a red colour.
- Ownership of the energy system and energy-using products are described with corresponding colours and dotted lines.
- Flows of products and services are pictured in the top-middle part of the map, showing transactions between provider and customer. In order to facilitate the reading of the map, flows are ordered with progression numbers.
- Payments are described in the bottom of the map, showing what the customers pay for and what modalities/channels are used.

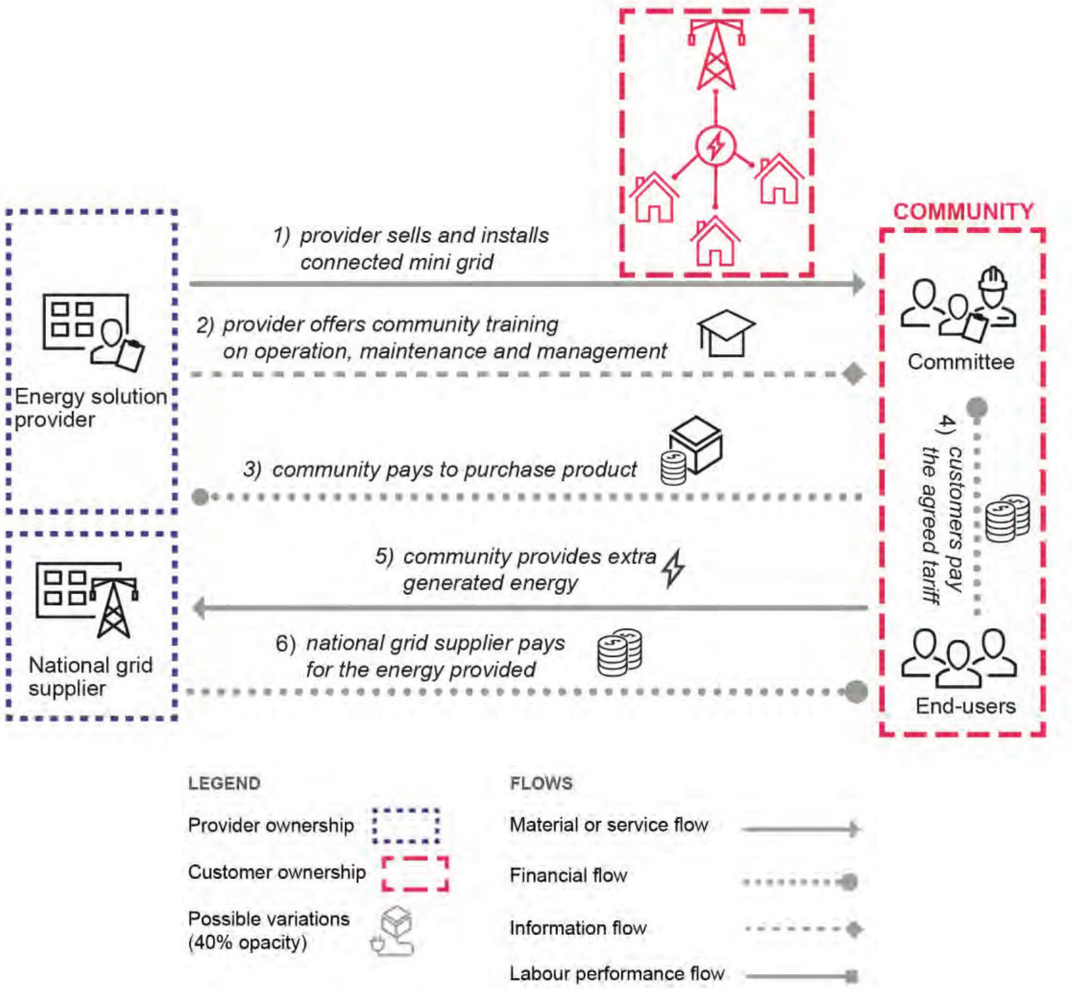

Figure 11 - Example of Energy System Map of a PSS+DRE model

5. Testing activities

The Energy System Map has been empirically tested during the course with companies and practitioners in Nairobi. As described in the methodology section, groups of participants designed new concepts of PSS applied to DRE and were asked to visualise their business model using the Energy System Map. The aim of the testing activities in Kenya was to assess the clarity, completeness and ease of use of the tool and to evaluate its applications in the design process.

5.1 Testing the clarity and ease of use

The first assumption was that the system map would help companies and practitioners in better understanding models of PSS and DRE compared to case studies described only with text. In fact, due to the high complexity of these models, the Energy System Map appears as an effective tool for clarifying the PSS offer, actors involved, ownership structure and payment modalities. Participants were given a set of four case studies and four system maps and were asked to match the right case with the corresponding system map. The time for this activity was 15 minutes. Cases were very similar to each other and presented differences in payment modalities, ownership structure or actors involved (example in Fig. 4). At the end of the session, all groups paired the cases with their relative system map correctly.

Participants were asked to rate the ease of this activity and most of them agreed that the exercise was easy to be done (average rating 4.2 out of 5) and commented that "*were easy to understand" and "clear to use".*

This exercise helped to clarify the use of Energy System Map for visualising and communicating PSS applied to DRE and in particular how this tool can be used in the design process (discussed below).

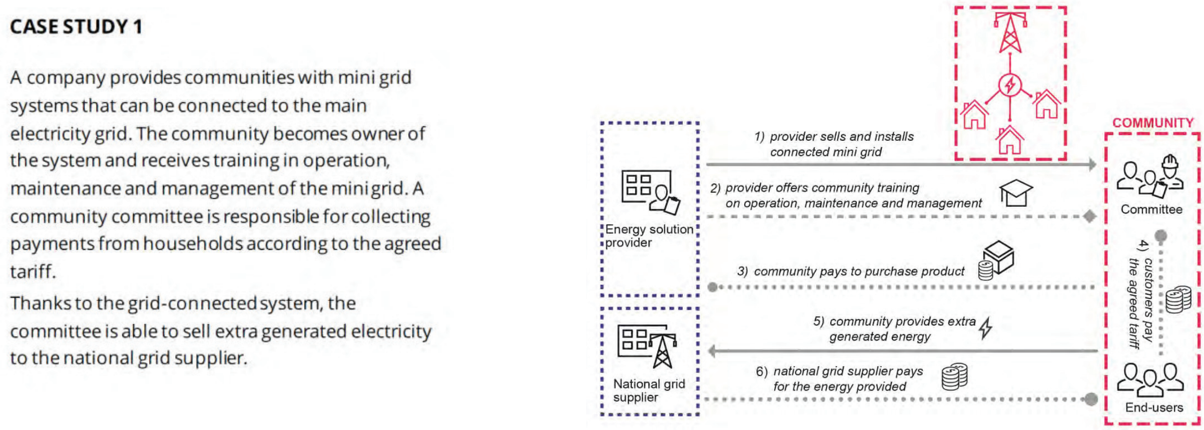

Figure 12 - Example of case study matched with corresponding system map

5.2 Applications

<u>1. Communicate case studies of PSS applied to DRE in a clear and effective way.</u>
The first application of the Energy System Map is for visualising and communicating PSS applied to DRE in a simple and effective way. Participants were asked to rate the use of the tool for better understanding case studies and most of them rated 4=good (60%) and 5=very good (40%), highlighting that "*the system map gives you a visual picture of how the case study looks like. It gives you an overview of the whole business model*". Some particularly commended the fact that the tool gives a single visualisation of a complex model ("*it enabled visualisation of the entire business model in a single snapshot. Helped refine and define interrelationships between actors in a simple way*") and that it helps clarifying relationships amongst actors and stakeholders ("*I can more clearly understand the important relationship and interrelationships between key stakeholders, products and services, value proposition and the customers*"; "*the system map clarifies synergies among player for each case study*").

<u>2. Design and detail new concepts of PSS applied to DRE.</u>
During the workshop in Nairobi, companies designed a new business concept and were asked to visualise their model using the Energy System Map. Participants were given a set of icons, a template to build their system map and a set of rules on how to describe flows and interactions (Fig. 5). The activity, which lasted about 2 hours, resulted in a detailed PSS concept (see example Fig. 6).
In the evaluation session, participants rated the usefulness of the Energy System Map for clarifying business concepts with an average of 4.5 out of 5 and most of them highlighted how the tool helped them in refining their concept ("*using the system map you are able to put together concepts or ideas that might be elusive during the brainstorming session*"). Furthermore, participants commented that the tool was helpful to clarify roles and relationships of stakeholders (*"[the system map is] a great deal on clarification of the concept"; "it helped in mapping the stakeholders and players"; "enables all actors to be given a role with clear relationships"*).

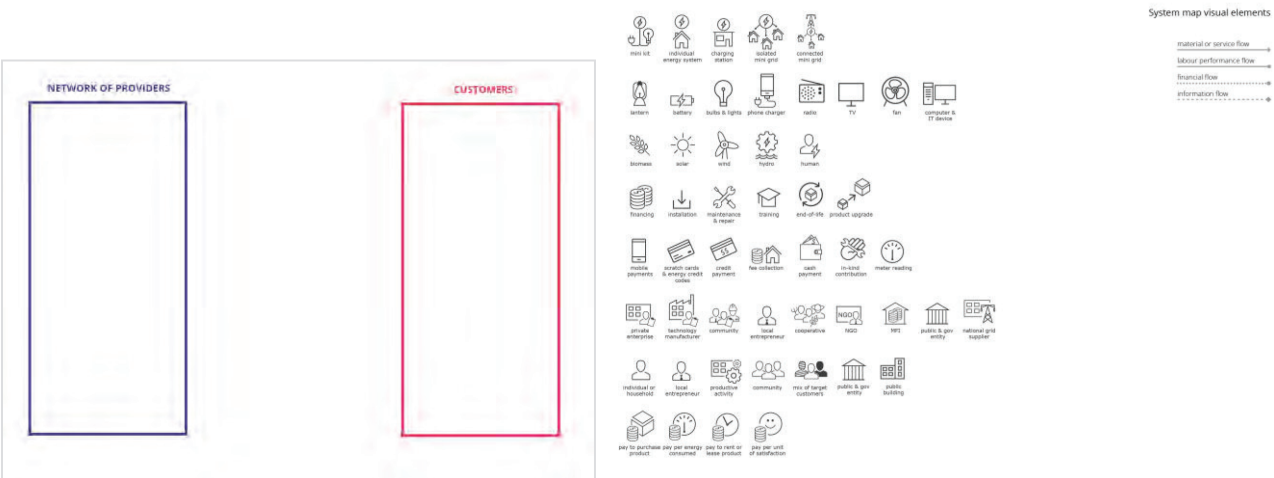

Figure 13 - The tool provided to participants: the template and the set of icons

The testing activities in Nairobi demonstrated that the Energy System Map can have an important role in the design and communication of these types of business models and most companies expressed their interest in using the tool in the future (see Table 1) but further work is needed for improving clearness and applications of the tool. For example, some companies highlighted the need to personalise and add more icons ("*needs to have the flexibility to add others in a unique case*"; "*[need] more icons related to other areas of renewable energy products + services other than grid related products*"). Others suggested to provide a software tool and a guide on how to use it. These feedbacks helped to consider further improvements and plan future activities (see next section).

Table 5 - Results from the questionnaires

Question	1=very poor	2=poor	3=sufficient	4=good	5=very good	Avg.
1. To what extent was the association of system map with the case study easy to be done?	-	-	1 (10%)	6 (60%)	3 (30%)	**4.2**
2. To what extent the system map helped you get a better understanding of the case studies?	-	-	-	6 (60%)	4 (40%)	**4.4**
3. To what extent the system map helped you to clarify your final concept?	-	-	-	4 (45%)	5 (55%)	**4.5**
4. Would you use the system map to visualise your business concept in the future?	Yes (9/10)			No (1/10)		

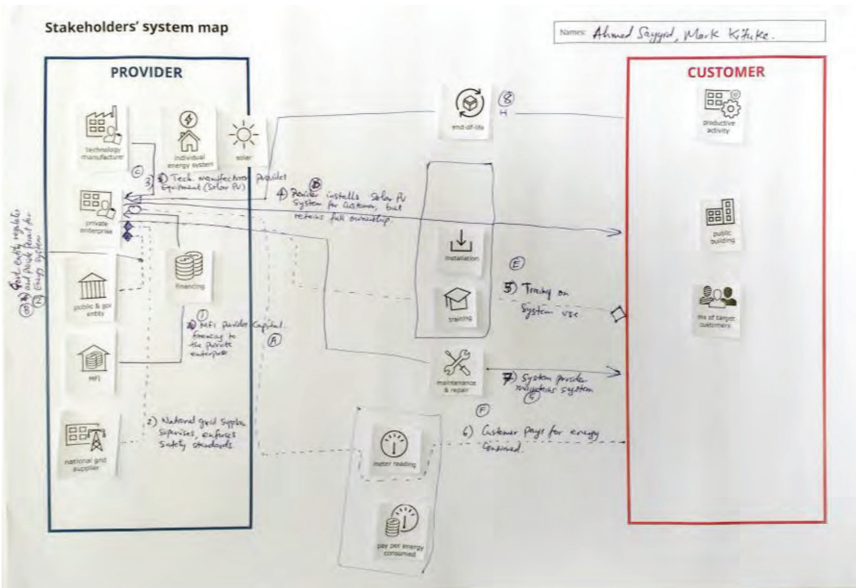

Figure 14 - Energy System Map designed during the course

5.3 Design considerations

Some interesting considerations emerged from the testing activities, not only in terms of graphic design improvements (such as icons) but also about the overall communication system and its use.
In particular, from the observations during the workshop and the feedbacks collected from participants, the following points should be considered:

- A set of rules and indications on how to design the Energy System Map should be provided in order to avoid first-time users to get confused about system barriers, types of flows etc.
- The use of 'provider' and 'customer' frames might limit the design process and system barriers were not clear in terms of which actors should be included within the frame. For example, some participants located 'government entities' in the providers' square even though their role was only to provide legislations and

policy advice, therefore they should not be included in the main offer but only considered as secondary stakeholders. Further improvements can explore different ways of placing providers and customers.

- In the current visualisation, flows of products and services are located in the upper-central space of the map. This created some confusion in more complicated systems, for example when a local entrepreneur is involved. Some design considerations should focus on whether the present structure is the best option for visualising PSS+DRE models or others should be explored.
- An assessment of icons and their clearness/effectiveness should be considered.

6. Conclusions and further research activities

In this paper we present the Energy System Map as a visualisation tool for designing PSS applied to DRE. The tool is composed by a set of icons, flows and rules for graphically representing PSS+DRE models and it has been applied with companies and practitioners in Kenya. The testing activities demonstrated that the Energy System Map can be used to clearly and effectively understand models of PSS and DRE and for (co)designing these types of business models. The feedback collected during the course in Nairobi helped to clarify needs for improvements of the tool and further testing activities with a wider range of companies and practitioners.

7. Acknowledgements

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8. References

- Ackermann T., Andersson G., Söder L. (2001) Distributed generation: a definition. Electric Power System Research 57 194-204
- Beck F. & Martinot E. (2004) Renewable Energy Policies and Barriers. Encyclopedia of Energy, Volume 5. Elsevier Inc.
- Castillo L.G., Diehl J.C., Brezet J.C. (2012) Design Considerations for Base of the Pyramid (BoP) Projects. Proceedings of the Cumulus Helsinki 2012 Conference
- Ceschin F., Resta B., Vezzoli C., Gaiardelli P. (2014) Visualising Product-Service System Business Models. Proceedings of the 19th DMI: Academic Design Management Conference Design Management in an Era of Disruption, London, 2–4 September 2014
- Friebe C. a., Flotow P. Von, & Täube F. a. (2013) Exploring the link between products and services in low-income markets—Evidence from solar home systems. Energy Policy, 52, 760–769.
- Heiskanen E., Jalas M. (2000) Dematerialisation through Services: A Review and Evaluation of the Debate. Helsinki: Ministry of the Environment, Environmental Protection Department.
- IFC & WRI (2007) The Next 4 Billion — Market Size and Business Strategy at the Base of the Pyramid. Washington, USA: International Finance Corporation and World Resources Institute
- Emili S., Ceschin F., Harrison D. (2016) (a). Product-Service Systems applied to Distributed Renewable Energy: a classification system and 15 archetypal models. Energy for Sustainable Development 32, 71-98
- Emili S., Ceschin F., Harrison D. (2016) (b) Supporting SMEs in designing sustainable business models for energy access for the BoP: a strategic design tool. Conference proceedings of Design Research Society (DRS2016), 27-30 June 2016, Brighton UK
- Emili S., Ceschin F., Harrison D. (2016) (c) Supporting SMEs in designing Product-Service Systems applied to Distributed Renewable Energy: Design Framework and Cards. LeNSes conference proceedings. 28-30 September 2016 Cape Town, SA
- Jagtap S., Larsson A.(2013) Design of Product Service Systems at the Base of the Pyramid. International Conference on Research into Design, Chennai, India. A. Chakrabarti and R. V. Prakash (eds.), ICoRD'13, Springer India.
- Jégou F., Manzini E., Meroni A. (2002) Design plan, a tool for organising the design activities oriented to generate sustainable solutions, working paper, SusProNet conference, Amsterdam
- Krucken, L. and Meroni, A. (2006) 'Building stakeholder networks to develop and deliver product-service-systems: practical experiences on elaborating pro-active materials for communication', Journal of Cleaner Production, Vol. 14 No. 17, pp. 1502-1508.
- Manzini E., Jégou F., Joore P., Luiten H., Rampino L., Valota P., Rocchi S., Lindsay C., Indekeu E., Meroni A., Cervetta G., Marchesi A., Marien M., Vidal L., Lambert J., van der Horst T. (2004) Food Delivery Solutions. GROWTH Programme, Cranfield University UK. Printed by Oscar Press UK
- Myers S. (2013) The Economic Challenge of Rural Electrification : Community Solutions Initiative in Africa. Global Humanitarian Technology Conference (GHTC), IEEE.
- Moe H.P., Boks C. (2010) Product Service Systems and the Base of the Pyramid: A Telecommunications Perspective. CIRP IPS2 Conference 2010.
- OECD/IEA (2010) World Energy Outlook 2010. IEA Publications, Paris.
- Schäfer M., Kebir N., Neumann K. (2011) Research needs for meeting the challenge of decentralized energy supply in developing countries. Energy for Sustainable Development, 15(3), 324–329.

- Schafer C., Parks R., Rai R. (2011) Design for emerging Bottom of the Pyramid markets: a Product-Service System (PSS) based approach. Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference. Washington DC 2011.
- Stahel W.R, et. al. (2000) From Manufacturing Industry to a Service Economy, from Selling Products to Selling the Performance of Products. Geneva: Product-Life Institute.
- Terrado E., Cabraal R. A., Mukherjee I. (2008) Designing Sustainable Off-Grid Rural Electrification Projects: Principles and Practices. Operational Guidance for World Bank Group staff, Washington.
- Tukker A. & U. Tischner (2004) New business for old Europe: Product Service Systems as means to enhance competitiveness and ecoefficiency. Final report of Suspronet.
- Tukker A., Tischner U., and Verkuijl M. (2006) Product-services and Sustainability. In: Tukker, A., and Tischner, U. (eds.) New business for Old Europe. Product Services, Sustainability and Competitiveness. Sheffield: Greenleaf publishers.
- Tukker A. & Tischner U. (2006) Product-services as a research field: past, present and future. Reflections from a decade of research. Journal of Cleaner Production, 14(17), 1552–1556.
- United Nations Environmental Programme (UNEP) (2002) Product-Service Systems and Sustainability. Opportunities for Sustainable Solutions. UNEP, Division of Technology Industry and Economics, Production and Consumption Branch, Paris.
- United Nations General Assembly (2014) Report of the Open Working Group of the General Assembly on Sustainable Development Goals.
- Vezzoli C., Ceschin F., Diehl. J.C. (2015) Sustainable Product-Service System Design applied to Distributed Renewable Energy Fostering the goal of sustainable energy for all. Journal of Cleaner Production.
- White A.L., Stoughton M., Feng L. (1999) Servicizing: The Quiet Transition to Extended Product Responsibility. Boston: Tellus Institute.
- Wong M. (2001) Industrial Sustainability (IS) and Product Service Systems (PSS): A strategic Decision Support Tool for Consumer Goods Firms. Cambridge, UK: University of Cambridge, Department of Engineering
- Zaring O., Bartolomeo M., Eder P., Hopkinson P., Groenewegen P., James P., de Jong P., Nijhuis L., Scholl G., Slob A., Örninge M. (2001) Creating Eco-Efficient Producer Services, report of an EU project. Gothenburg Research Institute, Gothenburg.
- Zerriffi H. (2011) Rural Electrification. Strategies for Distributed Generation. Springer International Publishing.