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Procedia CIRP 47 (2016) iii–vi

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Contents

Literature reviews on PSS

Maintenance and service through Lifecycle

Operations research/Management science approaches in PSS design and assessment

Organisational Issues and Transition Management

Product Service Systems and PLM

PSS Design and Engineering

PSS knowledge management

PSS Offering

Sustainability and PSS

The evolution of Product-Service Systems Business Models

The Role of Digital and Other Enabling Technologies in Product-Service Systems

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Procedia CIRP 47 (2016) 442 – 447

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Product-Service Systems across Life Cycle

Sustainable Product-Service System (S.PSS) applied to Distributed Renewable Energy (DRE) in low and middle-income contexts: a case studies analysis.

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Abstract

In industrialized contexts Sustainable Product-Service Systems (S.PSS) have been studied since the end of the 90's as business models with the potential to decouple the creation of value from the consumption of materials and energy, and thus significantly reducing the environmental load of the life-cycles of current product systems.

In the framework of the Sustainable Energy for All initiative (United Nations, SE4All decade 2014-2024), the EU funded, LeNSes project - the Learning Network for Sustainable energy systems (Edulink II programme, 2013-2016) has formulated the following Research Hypothesis: *"The S.PSS offer model applied to Distributed Renewable Energy (DRE) is a win-win approach to diffuse them (DRE) in low and middle-income (all) contexts, because it reduces/cuts both the initial investment cost of hardware purchasing and the life-cycle costs of maintenance, repair, upgrade, etc. while improving local skills and rising local employment, resulting in a key leverage for a sustainable development process aiming at democratizing the access to resources, goods and services."*

The paper describes the Research Hypothesis, the method adopted for the case studies analysis and the achieved results. The case studies analysis validate the hypothesis and shows various ways in which initial investment costs and life-cycle costs are reduced/cut when a S.PSS model is applied to DRE. These reductions/cuts are present both for Business to Business (B2B) and Business to Consumers (B2C) offers, as well as when the offer is the DRE system alone or when it is coupled with related Energy Using Products (EUP) or Equipment (EUE).

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Keywords: Sustainable Energy for All (se4all); Sustainable Product-Service Systems (S.PSS); Distributed Renewable Energies (DRE).

1. A promising shift towards Sustainable Development

The international scientific community dealing with sustainable development agrees that "Sustainable Development is not possible without Sustainable Energy for All", e.g. the United Nations launched the Sustainable Energy for All Decade [1] and introduced the new Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all [2].

Though energy is the world's dominant industrial sector, current centralized and non-renewable energy systems are far from being able to take energy to all in a sustainable way [3,4,5]. Many authors [4,5,6,7] agree that we need a paradigm shift of the energy system towards the so called Distributed Renewable Energy (DRE) (Figure 1.).

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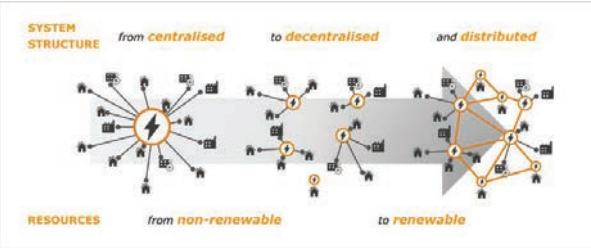

Figure. 1. Paradigm shift from non-renewable/centralized energy generation systems to distributed/renewable one

Distributed Renewable Energy (DRE) generation could be defined as follow [6]: "*Small-scale generation plants harnessing renewable energy resources (such as sun, wind, water, biomass and geothermal energy), at or near the point of use, where the users are the producers – whether individuals, small businesses and/or a local community. If the small-scale generation plants are also connected with each other (for example, to share the energy surplus), they become a Renewable Local Energy Network, which may in turn be connected with nearby similar networks.*"

To clarify, Distributed Renewable Energy (DRE) systems present the following environmental, economic and socio-ethical sustainability characteristics:

- They are based on inexhaustible resources consequently reducing greenhouse gas emissions and environmental impact for extraction, transformation and distribution;
- They are settled up as small-scale generation plants leading to a reduced economic investment;
- They are easy to install, maintain and manage consequently allowing local individuals and communities to install/manage plants. This characteristic fosters democratisation of access to resources while enhancing local employment and dissemination of competences.

Even though some first experiences to diffuse DRE have been settled up and implemented, there is still an evident gap of theory and practice on offer models to speed up effectively DRE diffusion especially in low and middle-income contexts.

This paper, as further explained in the next section, assumes the Research Hypothesis of the Learning Network on Sustainable energy system - LeNSes project, that Sustainable Product-Service Systems (S.PSS) are promising offer models to diffuse Distributed Renewable Energies (DRE) in low and middle-income contexts.

In fact, Sustainable Product-Service Systems (S.PSS) have been studied since the end of the 90th as (one of) the most promising offer/business models in this perspective. They have been defined as follow [3]: "*Sustainable Product-Service System (S.PSS) are offer models providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions*"

So forth, Sustainable Product-Service System (S.PSS) are value propositions introducing relevant innovation on different levels (Figure 2.):

- They shift the business focus from selling only products to offering a combination of products and services jointly capable of achieving a final user satisfaction, or better still a so-called "unit of satisfaction";
- They shift the primary innovation from a technological one to an innovation at stakeholders level, or better still in terms of an innovative stakeholders configuration;
- They shift the value perceived by the customer from individual ownership to access of goods and services.

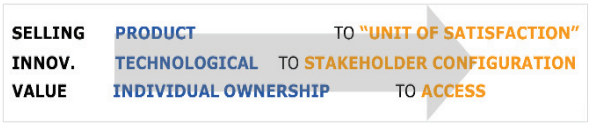

Figure 2. S.PSS innovation on different levels.

Here an example may clarify what we above.
RICOH PAY PER PAGE S.PSS *offers a package deal (Pay per Page Green) and installs, maintains and collects at the end-of-life the printers and photocopiers (not owned by the customer); the customer pays for the number of delivered pages and copies. The innovative interaction between the company and the client, make the company' economic interest to provide (and design) long lasting, reusable and recyclable photocopiers. In fact, as far as the company is not payed per photocopier or printer sold, but for the number of pages printed it is an economic advantage for the company the duration of the product, as well as the possibility to recycle the materials.*

Finally, S.PSSs are known offer models potentially decoupling resources consumption from its traditional connection with profit. Moreover, if properly conceived, S.PSSs can offer to low-income people the possibility to have access to services that traditional product sales models would not allow. Thus, in low and middle-income contexts *"a S.PSS innovation may act as a business opportunity to facilitate the process of a socio-economic development by jumping over the stage characterised by individual consumption/ownership of mass produced goods - towards a 'satisfaction-based' and 'low resource-intensity' advanced service-economy"* [8].

The Research Hypothesis couples the S.PSS and the DRE models as a win-win strategy and the case studies analysis presented in this paper has been made to validate and characterize it.

2. The LeNSes project Research Hypothesis

The Learning Network on Sustainable energy systems - LeNSes EU funded project (Edulink II, 2013-2016, www.lenses.polimi.it), an African-European multi-polar network of HEIs aiming at curricula development on System Design for Sustainable Energy for All (SD4SEA), has proposed the following Research Hypothesis [6]: *"The S.PSS offer model applied to Distributed Renewable Energy (DRE) is a win-win approach to diffuse them (DRE) in low and middle-income (all) contexts, because it reduces/cuts both the initial investment cost of hardware purchasing and the life-*

cycle costs of maintenance, repair, upgrade, etc. while improving local skills and rising local employment, resulting in a key leverage for a sustainable development process aiming at democratizing the access to resources, goods and services."

The LeNSes project, that involves four African and three European universities of design[*], is focused on to contribute to curriculum and lifelong learning capacity development in design for sustainable energy for all, i.e. to favour the building up of a new generation of practitioners capable of extending the access to locally-based, secure and cleaner energy services, based on the promising models of Sustainable Product-Service Systems (S.PSS) and Distributed Renewable Energy (DRE), addressing equity and gender issues.

The following aspects highlight main reasons why Sustainable Product Service System applied to Distributed Renewable Energies opens new opportunities in low and middle-income contexts:

- The offer focus is on (energy) access rather than (DRE) hardware ownership; this reduces/avoids initial investment costs, so that all can access renewable energy more easily;
- The offer sells (energy) services (units of satisfaction) rather than the (DRE) hardware; this reduces/avoids customer' unexpected costs for life-cycle services (e.g. maintenance, repair, …) of (DRE) products that may lead to the interruption of use;
- The offer development within a specific context of use leads to the involvement of local rather than global stakeholders; this favours local production and employment, as well as local skills and competences.

3. Case studies method

To validate and characterize the Research Hypothesis a case studies analysis has been conducted, as appropriate method for studying new areas and issues where little theory is available [9].

3.1 Objective

The overall objective of the case studies research was to analyse case studies of S.PSS applied to DRE in low and middle-income contexts, in order to verify and generalize their main characteristics, and consequently validate and refine the Research Hypothesis.

To improve validity of the overall objective, it has been verified within the defined system boundaries as: when S.PSS is applied to DRE as both Business to Business (B2B) and Business to Consumers (B2C) offers, as well as when the offer is the DRE system alone or when it is coupled with related Energy Using Products (EUP) or Equipment (EUE).

[*] LeNSes partners: Cape Peninsula University of Technology (South Africa), Makerere University (Uganda), University of Botswana (Botswana), University of Nairobi (Kenya), Brunel University (United Kingdom), Delft University of Technology (the Netherlands).

3.2 Process

Firstly, to facilitate the analysis and comparison of the case studies, a specific case study format has been designed and is structured as follows: *general information*, *system characteristics*, *competitive factors*, *barriers and constraints encountered*, *business model, sustainable benefits*. Furthermore, in relation to system boundaries, a polarity diagram was drawn (see Figure 3.). The first axis shows actors relations: the customer as final user (B2C) at one pole, and as small entrepreneur or small business (B2B) at the other. The second axis presents the S.PSS applied to DRE offer: at one pole, the offer as a DRE micro-generator (e.g. solar panel system plus its components such as a battery, inverter, etc.) and components; at the other pole, as the sum of both the DRE micro-generator and the related Energy Using Products or Equipment (e.g. phone and lights are Energy Using Products; refrigerator and printer are Equipment). The case studies selection covers all four quadrants; particularly quadrant 2 (bottom – left) was, as expected, the most represented. The case studies have been firstly analysed through desk-research including companies' websites and internal documents, scientific papers, and case studies made by other researchers [10,11,12,13,14,15,16,17,18]. On a second stage, semi-structured interviews have been done with relevant companies' personnel (e.g. CEOs, directors, project managers, etc.). In the last step, a record has been developed for each case study using the case study format, now available free of charge and copy-left at www.lenses.polimi.it.

Finally, to favour the interpretation of results related to the research objective a comparison between *Traditional product sale of DRE* and *DRE offered through an S.PSS* is proposed and discussed in section 5.

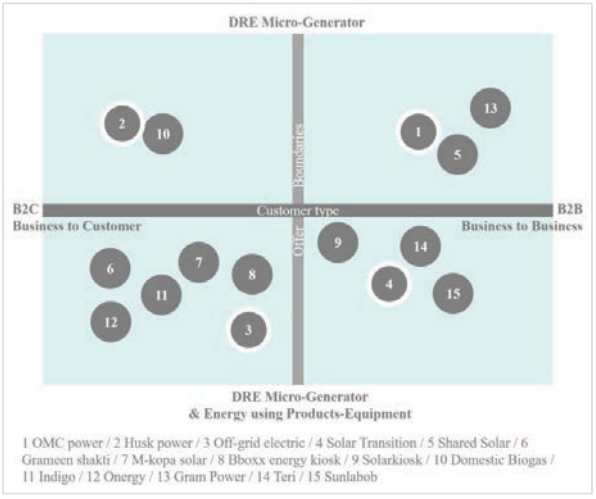

Figure 3. Collected case studies positioned within the polarity diagram.

4. Case studies collected

Table 1 compares 4 representative cases (one for each quadrant of the polarity diagram) of the 15 cases studied from India, Africa, South and Central America.

Table 1. Four illustrative case studies of S.PSS applied to DRE

Case study	Position within the Sustainable Energy for All Design Scenario	Description
Husk Power	Business to Customer offer including DRE micro-generator (quadrant 1 top – left)	Husk Power provides energy solutions by installing biomass power plants and then wiring villages to deliver electricity in India. Households pre-pay a fixed monthly fee, ranging from 2 to 3 USD, to get their house connected with full-day energy. The company retains ownership of the plants and employs local agents for operation, maintenance and fee collection. A partnership with local farmers is established to provide rice husk to power the plants.
Off-Grid Electric	Business to Customer offer including DRE micro-generator + Energy Using Products (quadrant 2 bottom – left)	The M-POWER company offers to Tanzania rural people Solar Home Systems (SHS) which include the hardware to generate energy (Solar panel + Storage + Wires) and related Energy Using Products (EUP - two lights + phone charger). Customers pay as a pay per period with a daily fee. OFF-GRID Electric retains the ownership of SHSs and EUPs including life-cycle services. OFF-GRID Electric organizes trainings for local dealers for installation and customer support, and has recently opened the first OFF-GRID Academy for technical training.
OMC Power	Business to Business offer including DRE micro-generator. (quadrant 3 top – right)	OMC Power offers energy solutions to telecommunication companies in India, through large stand-alone power plants running on solar, wind and biogas. Telecommunication companies get the power plant installed on site and pay according to the energy they use (kWh). OMC Power retains the ownership of the energy system and provides operation and maintenance. As complementary service OMC Power offers charged lanterns to local communities (pre-payment or pay-per-use).
Solar Transition	Business to Business offer including DRE micro-generator + Equipment (quadrant 4 bottom – right)	Solar transition, is a village recharging station based in Kenya, that provides renewable energy for a range of daily services: lantern and battery charging and renting, charging of phones, IT-services (typing, printing and photo-copying), tv shows. The recharging station is equipped with the hardware to generate solar energy (Solar panel + Storage + Wires) and a configurable series of Energy Using Equipment (EUE). The recharging station is owned and managed by the community itself who becomes local entrepreneur with competences on maintenance and repair. Customers pay an initial membership fee; then they pay for each service they use (pay per use)

Table 2 presents the complete list of case studies highlighting: *S.PSS typology, Initial investment amount, Impact on the field*. Three S.PSS typologies [19] have been considered within the analysis: *Product-oriented PSS* (i.e. services providing added value to the product life cycle), *Use-oriented PSS* (i.e. services providing 'enabling platforms' for customers), *Result-oriented PSS* (i.e. services providing 'final results' for customers). Furthermore, within the PSS typology the actors relation within the offer are highlighted in terms of B2B or B2C PSS.

Table 2. Collected case studies of S.PSS applied to DRE

Case study	S.PSS typology	Initial investment (euro currency)	Impact on the field		
			Start year	Current impact	Number of employees
Husk power	Result-oriented PSS (B2C)	2.875.000	2007	84 plants > 30.000 households	385
OMC power	Result-oriented PSS (B2C)	Not available	2011	> 11 plants > 150.000 households	80
Off-Grid electric	Use-oriented PSS (B2C)	8.300.000	2012	> 10.000 households	90
Solar transition	Product-oriented PSS (B2B)	42.500	2012	2015 > 250 users	5
Shared solar	Use-oriented PSS (B2B)	5.000.000	2012	9 centers > 250 households	13
Grameen shakti	Product-oriented PSS (B2C)	Not available	1996	46 centers > 1.000.000 households	3.500
M-kopa solar	Product-oriented PSS (B2C)	Not available	2011	> 300.000 households	650
Bboxx energy kiosk	Product-oriented PSS (B2C)	Not available	2010	42 shops > 50.000 households	84
Solarkiosk	Use-oriented PSS (B2B)	Not available	2011	107 E-HUBBs	535
Domestic biogas	Product-oriented PSS (B2C)	Not available	1992	> 270.000 households	Not available
Indigo	Product-oriented PSS (B2C)	200.000	2011	> 10.000 household	Not available
Gram power	Result-oriented PSS (B2C)	80.000	2012	30 plants > 60.000	Not available
Onergy solar	Result-oriented PSS (B2C)	Not available	2009	> 50.000 households	70
Teri	Product-oriented PSS (B2B)	Not available	2008	> 850.000 households	3000
Sunlabob	Use-oriented PSS (B2B)	4.000.000	2000	340 centers > 10.000 households	70

An extended description of all case studies is available at www.lenses.polimi.it, section case study.

5. Interpretation of results

A case studies analysis was performed to validate the Research Hypothesis. To support the interpretation of results a comparison between a *Traditional product sale of DRE* and a *DRE offered through an S.PSS* has been conducted and is presented in Table 3. The analysis shows that a *Traditional product sale of DRE* consists in the sale of a Distributed Renewable Energy (DRE) system with related components (e.g. solar panels with wires, inverter, storage) and installation and maintenance services. On the contrary, a *DRE offered through an S.PSS,* consists in a sustainable offer model applied to a DRE system, based on different configurations (of actors and offers), guarantying (DRE) access with a reduced/avoided investment and life-cycle services costs.

Table 3 displays these two alternatives and shows how each is related to the following variables, defined accordingly to the specific objectives of this study: *initial investment, ownership of the DRE micro-generator, life-cycle services of the DRE micro-generator, ownership of the Energy Using Products or Equipment, life-cycle services of the Energy Using Products or Equipment, DRE system production*.

Table 3. Traditional product sale of DRE and DRE offered through an S.PSS.

	a) **Traditional product sale of DRE**	b) **DRE offered through an S.PSS**		
		Product-oriented PSS *services providing added value to the product life cycle*	**Use-oriented PSS** *services providing 'enabling platforms' for customers*	**Result-oriented PSS** *services providing 'final results' for customers*
(1) **initial investment**	customer	provider	provider	provider
(2) **ownership of the DRE micro-generator**	customer	customer / local entrepreneur	provider	provider
(3) **life-cycle services for the DRE micro-generator**	customer	customer / local entrepreneur	provider	provider
(4) **ownership of the Energy Using Products or Equipment**	customer	customer / local entrepreneur	provider	provider
(5) **life-cycle services for the Energy Using Products or Equipment**	customer	customer / local entrepreneur	provider	provider
(6) ***examples***	*Traditional product sale of DRE*	*Solar transition (B2B) Bboxx (B2C)*	*Solarkiosk (B2B) Off-grid Electric (B2C)*	*OMC Power (B2B) Husk power (B2C)*

In the following, results are interpreted analysing the impact of the variables on traditional product sale of DRE and on the three ways in which a DRE can be offered through an S.PSS.

The variable *(1) Initial investment* regards the setup of a DRE system, i.e. the purchase of the Distributed Renewable Energy micro-generator and its components (e.g. solar panel with wires, inverter, storage). In a traditional product sale of DRE this cost is covered by the customer, who becomes owner of the (DRE) system. To provide an affordable solution, especially in low and middle-income contexts, when an S.PSS is applied to DRE, the initial investment cost stays with the provider and customers pay only to access the DRE system. They can pay a fixed fee (e.g. daily/weekly/monthly payments to access energy every day) or, they can pre-pay to access energy for a predefined period of time (e.g. to access 3 days of energy). Even for Product-oriented PSS, where the customer becomes the owner of the (DRE) system, the initial investment cost is covered by the provider, and is paid back by the customers according to his specific needs (e.g. fixed fee/pay per period/…). On the provider side, this initial investment to buy/build the (DRE) system is coherent with a growth strategy. With this business model the provider 1) expands his market and reaches customers who would not be able to sustain the cost of a new system or would not be able to pay it in one instalment 2) creates longer term relationship with the clients, ensuring a stable income for himself during the whole life-cycle of the (DRE) system 3) increases the shares of potential customers because the satisfied customers promote his service with other customers 4) strengthen his market position, through the development of strategic partnerships (e.g. national governments, investors, etc.).

All case studies have shown that cutting the initial investment is a key factor to diffuse DRE access in low and middle-income contexts. For example one of the provider's managers told us "the customers of Off-grid Electric, who were used to buy kerosene for lanterns, now can access Distributed Renewable Energy at an affordable price since, without initial investment (retained by Off-grid Electric) energy cost remains same of how much they already spent, while improving their quality of life (i.e. reduction of health diseases, improvement of education).

The variable *(2) ownership of the DRE micro-generator* and its components (e.g. solar panel with wires, inverter, storage) as well as the variable *(3) life-cycle services for the DRE micro-generator* and its components, in traditional product sale of DRE, are in charge of the customer. On the contrary, when a Use-oriented or Result-oriented PSS is applied to DRE, the life-cycle costs are in charge of the provider who retains the ownership of the (DRE) system; this cuts unexpected life-cycles costs (e.g. repair) for the customer. An intermediate solution emerges when a Product-oriented PSS is applied to DRE. In this case, the life-cycle costs are replaced by small periodic payments, usually affordable for the customer (e.g. warranty contract). On the provider side, since

the provider, or a partnership of providers, retains the ownership, or at least retains some responsibility over life-cycle of the (DRE) system, there is an economic incentive to 1) extend (DRE) product's lifetime, postponing both the disposal costs and the costs of manufacturing new products 2) provide high quality products with low life-cycle costs to reduce the costs (e.g. repair) and obtain higher margins.

In relation to the management of unexpected costs some differences have been identified among the three S.PSS typologies e.g. when a Product oriented PSS is applied to DRE unexpected costs are replaced by small periodic payments by the customers as warranty contract; while, when a Use-oriented or Result-oriented PSS is applied to DRE, unexpected costs are covered by the provider. For example one of the provider's manager told us that "in Husk Power (Result-oriented PSS), power plants are owned by the provider and life-cycle services are covered as well, this avoids unexpected costs for the customer/local entrepreneur, reducing interruptions in the products use. On the contrary, for example in Bboxx case study (Product-oriented PSS) the life-cycle services of the DRE system stay with the customer/local entrepreneur who owns the DRE system. To avoid unexpected costs for the customer, he/she can go for a warranty contract. More than 50% of the customers has opted for this solution.

The variables *(4) ownership of the Energy Using Products or Equipment (EUP-EUE)* and *(5) life-cycle services of the Energy Using Products or Equipment*, follow similar logics to variables *(2)* and *(3)*; applying them to Energy Using Products (e.g. phone and lights) and/or Energy Using Equipment (e.g. refrigerator and printer) of a (DRE) system.

A final consideration from the case studies is related to their *Impact on the field* (e.g. Table 2). The involvement of (local) intermediary, favouring local employment and empowerment, has resulted as key characteristic in most of the case studies (see Table 2.). For example – the Grameen Shatki case study has involved (local) women, training them as local entrepreneurs and technicians. Currently, the majority of them is running her local energy enterprise (e.g. technical assistance for SHS), enlarging Grameen Shakti diffusion.

6. Conclusion

Even though further studies are suggested to further understand all implications, the case study analysis clearly shows that S.PSS applied to DRE is promising strategy to speed up diffusion, and guarantee long time use of Distributed Renewable Energies in low and middle-income contexts. This has been verified especially in relation to: the characteristic of S.PSS applied to DRE of cutting both the initial investment cost of access to energy and the unexpected life-cycle costs of (DRE) products (e.g. repair), avoiding or reducing the probability/risk of use drop off.

The implementation of S.PSS applied to DRE experimentations is currently on going worldwide, showing new opportunities for improvement and further research. Most analysed cases were designed and settled up by "Western/developed" countries of the world. This, above other reasons, could be caused by the required initial investment, both in economic and knowledge terms, not often affordable or available in low and middle-income contexts. So forth, has been furtherly recognized the need to develop (local) new knowledge and know-how both for the design, implementation, and life-cycle management of S.PSS applied to DRE offers. This opens a new role, knowledge base and know-how for an incoming generation of designers as well as to the emerging discipline of System Design for Sustainable Energy for All[†] (SD4SE4A).

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[†] System Design for Sustainable Energy for All (SD4SE4A), promotes a 'stakeholder configuration' approach, which means designing the interactions of the stakeholders in a particular satisfaction-system, combined with a 'system sustainability & energy 4 all' approach, which for economic and competitive reasons continuously seeks both socio-ethical and environmentally beneficial solutions that are powered by DREs for all.