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Product-Service Systems across Life Cycle

Development and Evaluation of Solar Energy B2B Solutions

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Abstract

In order to achieve successful product-service system (PSS) development and commercialization, a methodical approach is inevitable. This approach must be conducted in the development and testing processes of system components as well as in the entire system. Innovative solutions have to gain a high maturity in a minimum time period to put advantages over competitors into practice before they are outdated. In India, distributions of solar home systems are spreading dynamically, but are facing problems in their customer relations. Planning, installation and maintenance of the systems are all weak points in this field. Throughout this project called MEVIS, an integrated solution was developed in order to eliminate these problems: an innovative charge controller as well as an information system, which are both technical components of a business-to-business service solution. In addition to the technical function of the charge controller, the added value is achieved through the accessibility of employees to information, enabling them to more efficiently carry out processes by supporting their decision making or planning according to their individual roles. The overall design was carried out utilizing PSS development methods, elaborated at Fraunhofer IPK and TU Berlin, in order to enable a company to become a PSS provider. During the development process, the evaluation was carried out at several stages. According to the PSS V-model development, results have been tested at an early stage by a proof-of-concept and agent-based simulation technologies. The detailed modeling of components, actors and the environment in the design stage facilitate the creation of the simulation model. This represents the first virtual integration of the various domains in the development after the PSS V-model. With this integrated system model, extensive studies regarding the interaction of the components during the business processes can be conducted along various stages of the development process. The final field test of the overall system was conducted in Bangalore, India. The selected partner, Selco Foundation, has vast experience in distributing solar home systems and carries out all lifecycle activities on itself. To solve their problems in solar energy distribution, the partner uses the developed charge controller and gets the aggregated information according to the needs of the relevant service. The findings from the application of methods of development, evaluation and testing are described in this paper. It analyzes how the provider was enabled to make the transition from a service provider to a PSS provider. The analysis also evaluates how these methods have the power to support future providers to bring innovative business ideas for integrated solutions to a high maturity without having years of experience in PSS.

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Keywords: solar energy, PSS development, agent-based simulation, PSS evaluation, PSS piloting

1. Introduction

Integration of products and services to a product-service system (PSS) increased the added value and sustainability in several areas [1]. In the project MEVIS, this concept has been used to improve the supply of electrical power in rural areas of emerging countries. MEVIS means "Micro-Energy-Supply-System" and includes a holistic approach to decentralized energy supply by solar home systems (SHS) and was jointly conducted by the Fraunhofer Institute for Production Systems and Design Technology and the companies Micro Energy International GmbH and iPLON GmbH. The supply with electrical energy by SHS is widespread in emerging countries and enables the substitution of fossil fuels as well as participation in electronic information media in remote areas. However, this technology has some weaknesses:

Processes in the lifecycle planning, installation and maintenance are not performed sufficiently effective and efficiently. This leads to failures in the systems, unclear warranty cases, as well as a poor utilization of system resources. These problems should be addressed with the integrated approach of MEVIS. Physical product components, an information system and service processes were developed in the project in an integrated way. Thus, they can be matched perfectly in the conception and can be ensured at an early stage. In order to achieve a successful development project and to supply competitive solutions, methodological approaches were used.

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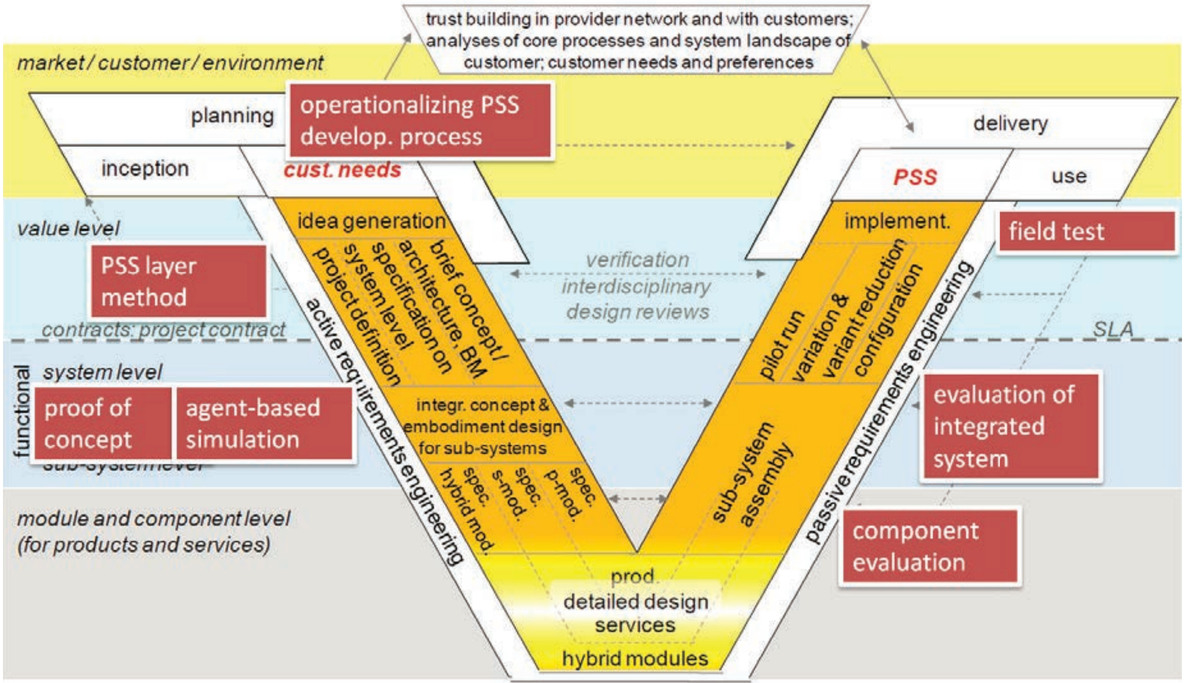

Fig. 1. Applied methods along the PSS v-model by Müller.

These methods were developed in the fundamental research project TR29. The layer method, for example, was developed and tested by Müller in cooperation with the company Micro Energy International in the preparation of the project MEVIS [2]. Hereinafter, the used approaches, the results and methods for ensuring are described.

1.1. Problems in the lifecycle of solar home systems

In an increasing number of households in emerging countries renewable electric energy is produced by solar home systems. These systems consist of a photovoltaic panel, a charge controller and a rechargeable battery. Fuel-based lighting is replaced reducing the primary source of greenhouse gas emissions [3]. Solar home systems further replace dry-cell batteries applied in conventional torches which involve a high risk of contaminating local water and soil resources with toxic heavy metals [3]. It is difficult to utilize the potential of sustainability for solar home systems in rural areas of developing countries. One aspect is poor transport infrastructure with long and poorly developed routes to individual customers that increase the service time, and thus the cost, for the provision of services in maintenance and repair. In addition, supply of high-quality system components and spare parts is not guaranteed [4]. Furthermore, inadequate training and migration cause a lack of trained service personnel. This results in a low density of specialized companies that ensure the maintenance of the systems [4]. Due to these circumstances, it is often more profitable for suppliers of solar home systems, to replace it in the case of malfunction than to repair it. This leads to an extensive consumption of resources, which reduces the economic and environmental sustainability. Besides, local people are deprived of the opportunity to be qualified and to set up their own service network.

1.2. Applied PSS development methods

The methods chosen for the development are based on the generic development methodology for PSS, which was developed at Fraunhofer IPK and the chair Industrial Information Technology of the Technische Universität Berlin. They arise from a v-model that maps the entire development process in a generalized representation. The customer needs are defined as one basis of development and are also the last instance for ensuring the fully integrated solution in the end [5]. The generic development process can be seen in figure 1 that is supplemented by the utilized development methods in the relevant stages.

In the beginning, it is important to analyze prerequisites for the realization of PSS. This is supported by a methodology on an operational level that transfers the generic process model into a detailed project plan. Within this plan, several tasks were described, how to set up the PSS development [6]. These were, for example, provider networks, the provider's capabilities and environmental conditions. Once these have been analyzed and evaluated, the identification of customer needs is performed by using case studies. Experiences of the project partner Micro Energy International through their close contact with the microfinance institutions also helps to find customer needs. As a next step, ideas have to be generated how values can be created to fulfill the needs. This task is supported by the PSS-layer-method.

2. Development of a PSS solution for decentralized energy supply

Part of the project MEVIS was to improve the dissemination of solar home systems by a methodological approach to the development of PSS. A solution was developed in which established providers of SHS in the target regions take the role of customers and the company Micro Energy International becomes as PSS provider. If a product-service system is to be developed, this requires thorough planning. The procedure for planning and implementing the development of the PSS is described hereinafter.

2.1. Planning the development process

Project planning is the key to start developing a technical solution. This plan determines the sequence of individual activities in the development process and the date for the project results. To support the planning it is useful to build up models for the development process. One approach to model the development process is a v-model, which was further enhanced by Müller [5] to the generic v-model for PSS development. In this model the development process is broken down starting from the system level to the domain level. The v-shape provides a better overview of the dependencies between development models on one side and system components in their different integration levels on the other side. Thus, the appropriate development model can be assigned in the validation process at any level of detail of the implemented system. So it should be noted in this model that the fully implemented system has to be ensured at the end with the basic customer needs. Thus, a maximum rate of success at the launch of the PSS is in sight.

This model, however, is very coarse and hardly helps in planning individual activities. A method for operationalizing PSS development processes supports these activities. The planning of prerequisites for the realization of PSS is important in early stages of the development process. It is supported by the transfer of the generic process model into a detailed project plan. Within this plan several tasks were described on how to set up the PSS development [6]. For example elaboration of provider networks, providers capabilities and environmental conditions was conducted. This process is followed by the transfer of all identified activities into a project plan. In order to make results predictable, activities were filed in time inside the project schedule. Milestones have been established to review the present results according to certain phases of the project.

2.2. Idea generation

At the beginning of the project, the idea was to further develop the charge controller of a SHS, in order to solve the problems with conventional systems. A solution should be approached not only from the technical but also from a process-oriented view. Hence the idea of a combined development of an innovative charge controller, an integrated service purposes concept and a supportive information system were created. Relationships between the system components and the actors are shown in figure 2. In order to obtain a better overview, the concept has to be arranged in a model including all relevant aspects of the PSS. The suitable method in this case is the PSS-layer-method. Its purpose is to support the clarification of design tasks and conceptual design. This method is used to analyze and synthesize PSS ideas and concepts. It enables a structured documentation of an existing or of a future PSS. It defines a model of nine main element classes for a PSS. As a result the developer gets a structured outline and the big picture of his PSS concept. This helps to highlight requirements and tasks for the PSS design [2].

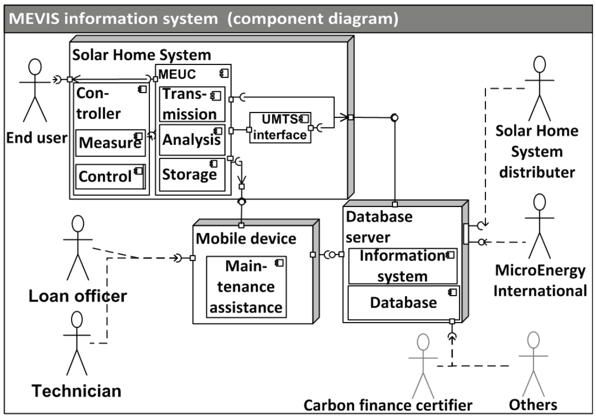

Fig. 2. Component diagram of information system.

Needs	• efficient resource planning
Values	• overview of system states
Deliverables	• processed usage data from all SHS
Lifecycle activities	• planning → installation→ use → maintenance
Actors	• provider, SHS-distributer, technician, end-user
Core products	• MESUS-charge controller, information system
Periphery	• Internet, mobile radio network
Contracts	• usage of MESUS-hardware and information services
Finance	• end-users pay for availability of electric power

Fig. 3. Layer method for brief description of solution idea.

Figure 3 shows an example of a PSS-layer model with specific descriptions for each layer. Going through iterative loops, the level of detail is raised. Finally, the requirements were derived from the model with the help of the requirements checklist. With this checklist specific topics concerning PSS are helping to identify and arrange requirements that can be derived from the PSS layer model. Examples are the consideration of legal parameters between all actors or responsibilities for actors in different lifecicle stages. The structured overview in the layer model helps to allocate responsibilities and links in subsystems and design models. Secondly, the model helps to develop a specific business model. It defines customer value, ownership, risk diversification and organizational activities. At the end of this process, a specification was created including a detailed description of the requirements of all components, the interfaces between themselves and between them and the environment, as well as the consideration of the boundary conditions.

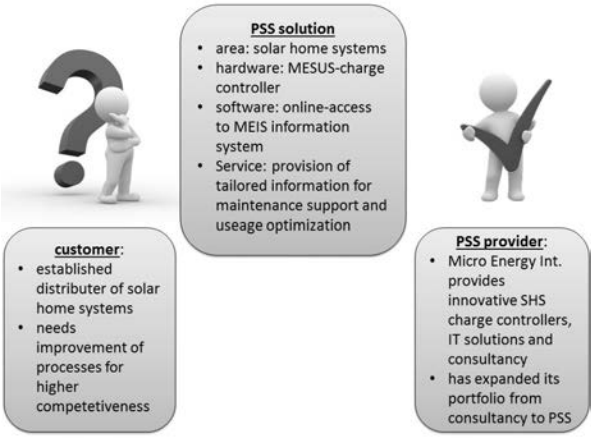

Fig. 4. Overview of PSS business model.

2.3. *Concept of a PSS solution*

At the beginning of the PSS development, the business model has been outlined initially. For this, the modeling language UML had served as a tool. In this way, an overview was created concerning the actors in the business process, their activities, the communication between the system components, as well as the added value. However, UML can represent only parts of the system clearly. Therefore, a PSS-layer model has been applied for a holistic picture of the initial idea. In this, the dependencies between the relevant parts of the system were mapped and separated according to the phases of the lifecycle. The subdivision of the system levels is shown in figure 3. Using the UML models, decisions were taken on how the PSS should be designed. The purpose is to clarify which roles the actors take over later on. In the current idea, there are two players who would be eligible for the role of the customer: whether the end user or the SHS-seller. Otherwise, both the SHS-sellers, as well as the hardware and IT provider MEI could act as the PSS provider. It was finally decided that MEI takes on the role of the provider and the SHS-seller would be the customer. This simplifies the processes in the data communication, because MEI is administrating the information system. In addition, tailored service packages for individual SHS-sellers can be offered. The advantages of reliable maintenance is thus passed on indirectly to end-users. An overview of the general business concept is illustrated in figure 4.

2.4. *Developed components of the PSS solution*

Business processes The required boundary conditions were determined by the method of operationalizing PSS development and are now available to support elaborating of solution elements. With the understanding of the necessary corporate structure, the legal and economic environment, as well as the infrastructure, the business processes were examined in detail. As a tool for modeling the processes, the modeling language BPMN was used. The results were a consistent business model which includes all activities of involved actors and IT communication in order to provide the PSS.

Charge controller The usual functions of charge controllers for SHS were extended to a number of functions. The new features for the measurement and transmission of operational data of the SHS are emphasized here. With sensors voltages, currents and temperatures are measured at relevant interfaces and stored in the device. The device contains a data interface for communication with a cellular network. Thus, the measured parameters are transmitted at specified times to the central database. Furthermore, the controller offers additional features, such as a hierarchy of consumers and free programmability of additional functions, such as alternative accounting systems.

Information system The information system consists of several parts that have been developed separately and integrated in retrospect. One part is the data communication between controller and database. This is done by sending JSON files, containing operating data of a day, over the cellular network. In the next step they were inserted into a NoSQL database on the server. The data is analyzed in order to give users a quick overview of the status of the system. For this purpose specific thresholds are specified by which the data is analyzed either immediately or in long-term observations. The information is displayed in user-group-specific user interfaces. The output medium is a browser interface and an application for a tablet PC. Both, information about the maintenance status of systems can be accessed, as well as contract data of end users are managed. In addition, the application includes an interactive support for the maintenance. This leads the engineer with an interactive guide through maintenance processes that are displayed with the help of Augmented Reality on the real system. By using the online analysis of operating data, the technician will be supported on site both during fault allocation, as well as during the troubleshooting process [7].

2.5. *Methods for evaluation of concepts and results*

As explained already in the introduction to the PSS model, the results of the development at various stages and levels of the system must be evaluated. This first occurs at the level of individual components. Here are the requirements and the functional descriptions of the specifications and requirements specification the basis by which a successful ensuring is assessed. Following the successful ensuring, carried out the integration of the components into subsystems and then to the entire system. In the case of PSS, the entire system is very complex by the service processes and requires ensuring methods that can represent this complexity in an appropriate setting. In return, the methods of the Smart Hybrid Prototyping [8] or conducting a pilot study [9] are suitable. Even in the early stages of development the concepts already can be ensured. The detailed modeling and documentation of concepts were helpful in this case. With these basics, a physical prototype of the electronic and information technology components was set up in the form of a proof-of-concept. Also, a virtual prototype of the PSS in an agent-based simulation model was created.

Proof-of-concept The prototype of the proof-of-concept was assembled from existing components of the company iPLON GmbH. Since the company has already worked in the field of data transmission of solar systems, the basic functionality of the controller could be mapped from existing products. The construction of the prototype is shown in figure 5. In the testing, the data communication with the information system should be analyzed. With this prototype, a prioritization of requirements was performed and revealed additional requirements for data

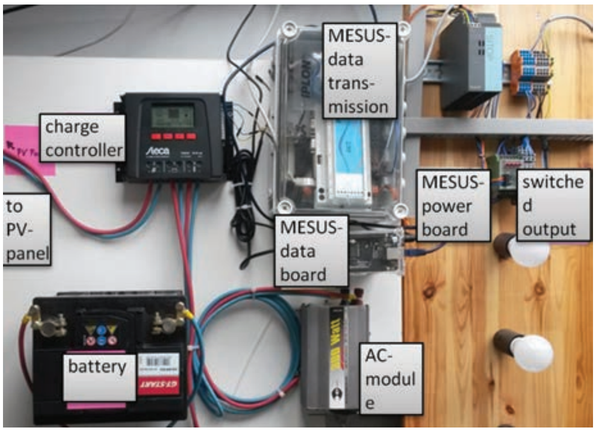

Fig. 5. Proof-of-concept of integrated technical components.

transmission over a cellular network. For example, protocols had to be determined, be with which control commands from the browser interface were sent to the controller.

Agent-based simulation One part of the business model is the provision of a concept evaluation for the resource planning of a solar home system distributor. For evaluation of service processes and their interaction with the technical components, an agent-based simulation model was developed. The simulation method of agent-based models is used to represent interaction between actors and artifacts. All actors and artifacts are represented by specific virtual objects, the agents. These move along defined paths or are set at fixed locations and interact automatically, according to the implemented features. while the simulation is running, desired parameters are measured to assess the system's suitability to its use case. These are displayed in diagrams to allow rapid evaluation of the simulated solution [10]. Following elements were mapped in the simulation: shop floor, technical staff, locations of installed SHS, network of weighted paths for service staff. These elements can be allocated with specific properties, for instance how to interact with each other in order to determine values that are important for the evaluation of the operation. Figure 6 presents a conceptual visualization of the simulation model for maintenance processes. The agents move autonomously along their predetermined paths and start to interact according to their presets when they meet another agent, like in this case a technician and the house of a customer. The results of the interaction are processed in the background and can be used to analyze the interaction of the whole system. The analysis can be applied for different objectives, for instance overall costs or maintenance time and can be displayed in diagrams. Specific properties have been assigned to the agents, e.g.: error type, repair time, priority and severity of the error. Properties of the technicians are income and skill level. Evaluation criteria of the customer are satisfaction and the overall cost for running the PSS which is determined by calculation models that take all interactions between the agents into account. The upper diagram in figure 7 shows the repair status of all houses and gives an overview over the number of repairs during the time period. The middle diagram shows cost and revenues for the repair activities and the lower diagram shows the calculated dissatisfaction index of the customers. In different scenarios with different parameters,

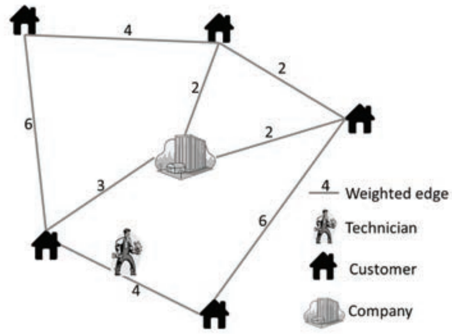

Fig. 6. Overview on represented entities in the simulation model.

these values were optimized. As a result of the simulation staff resources regarding their skill level and location were optimized in order to achieve the best cost-satisfaction ratio.

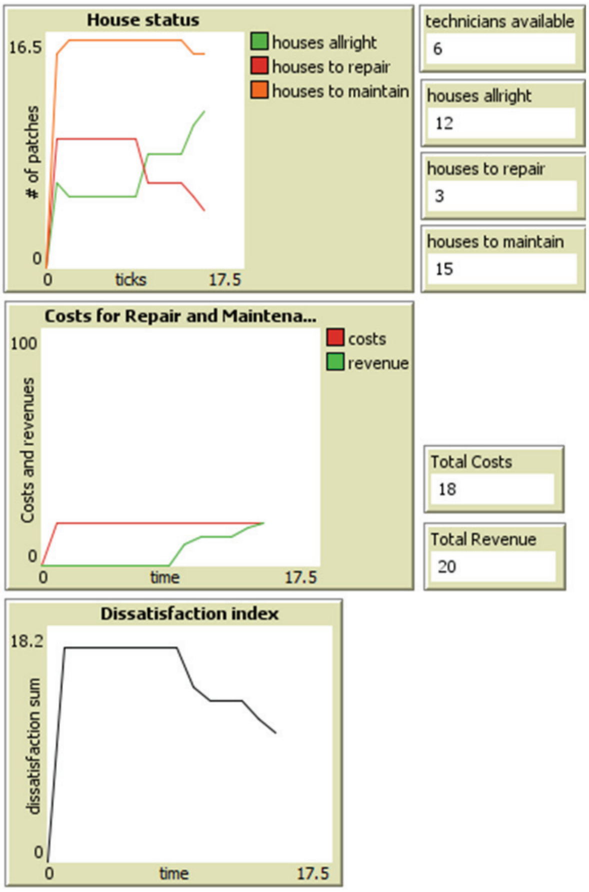

Fig. 7. Diagrams in the simulation environment for evaluation.

Milestone reviews During the project, the developed technical components are integrated via the interfaces and then tested. The release of a development level successes in the milestone meeting. At these meetings, the overall functionality of the inter-alloy system was jointly assessed and completed the development phase.

Pilot run As part of the preparations for the field test of the measurement systems, the applications and interfaces were discussed in a number of discussions with local partners. There were intensive discussions held with the SELCO-Foundation (India). Here, with reference to the first prototypes both technical interfaces as well as cultural aspects of usability were discussed. A special technical request was referring to the use of the systems in a 48 V micro grid which SELCO currently operates. Then SELCO Foundation has tested the system extensively under field conditions. It has been found that some aspects, such as the internal electricity consumption can not be covered by the usual batteries in India for a long time. The results were very important for the further project development, since all core issues relating to the hardware, the mobile reliability, and usability in India by social and economic standards, could be clarified.

3. Conclusion

With the completion of the project it could be shown that by means of the application of development methods for PSS, a current service provider can be enabled to ba a PSS provider. For this project, the planning and implementation was consistently methodological supported, which has led to successful results in the milestone meetings, as well as the completion of the whole project. The requirements, features and concepts have been consistently displayed in the virtual models and were fully documented. Thus it could also be successfully cooperated across disciplines. The PSS-layer method and the method of operationalizing PSS development have helped to substantiate the ideas and to design a promising solution in dependence on the determined boundary conditions. Especially the first stages of development including the requirement engineering and modelling took much more time than estimated, because of the little experience of the company in methodological product development. Regardless to the extra time that was needed in the beginning, the approach saved a lot of time in the later implementation because of the detailed plans, requirements and models. By using the PSS v-model, a focus was placed on the ensuring to the level of detail of the system from the outset. The thorough preparation of virtual models at the beginning of development have simplified the ensuring of concepts by early prototypes, such as proof-of-concept and the agent-based simulation model. Thus, the components of the PSS can be easily developed and integrated later on. The implementation of the pilot study at the end of the project has given much insight, both concerning the technical issues, as well as concerning the implementation of business processes in emerging markets companies.

The results of the project will be further developed in order to open up additional business cases with the solution. This includes the connection between SHS to one another in order to build up microgrids. These increase the reliability of power supply for the individual end users and thus helps to expand the energy supply through renewable energy sources. The methodological experience from the application and development of the PSS development methods were evaluated and should be applied and refined in future projects with industry partners from various industries.

Acknowledgements

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