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Flexibility provision from local energy communities exemplified by the SUSTENANCE and SERENE H2020 projects

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Abstract

When integrating a huge amount of fluctuating renewable energy, there is a need for mitigating the fluctuations by adapting the demand to the actual production. In the case of local production in households or a local energy community, the flexibility provision from the demand side should be optimized to ensure as much self-consumption as possible to minimize energy costs for the customer, but at the same time, the flexibility provision should also ensure needed hosting capacity of the nearby grid, by controlling the consumption and perform peak-shaving if possible. In the case of larger renewable power plants such as offshore wind farms, or large solar plants on land, the main flexibility provision has to be seen merely as a possibility to provide ancillary service to the electricity market as primary or secondary reserves. In several cases, prioritization is necessary in relation to whether the demand should be controlled according to the overall balancing or a local condition ensuring the hosting capacity.

The H2020 SERENE and SUSTENANCE projects look into flexibility provision from and scheduling of the energy consumption in local energy communities/areas at different demonstration sites in Denmark, The Netherlands, Poland, and India. In Europe, the local energy communities are grid-connected, and the optimization is mainly considering the control of heat pumps including their heat storage, EV-car charging, and in a few cases also the application of battery energy storage. The optimization is done in relation to cost optimization for the individual private costumers, which among others looks into enhancing the self-consumption of own produced energy – here mainly from PV power production, and at the same time, acts on the electricity market, buying energy when it is cheap, and selling in high price periods. Finally, the control also ensures that the local grid will not be overloaded, by also scheduling according to the local hosting capacity.

In India, there is also a grid-connected test site at the Indian Institute of Bombay, where the heat flow in a small house is controlled as well as car charging experiments. On the other hand, there are also two remote test sites in local villages, where there is no or only weak grid connection. Here the demonstration of flexibility provision is seen as a scheduling optimization on when to turn on the different demands, which include charging of electrical rickshaws, pumping of water, utilization of multi-purpose heat pumps for cooling and drying purposes as well as newly installed electric installations in the houses. Here the energy is generated by small wind turbines as well as PV panels, and battery energy storages are used to run the systems as microgrids.

In the paper we will show the different setup control methods, it will show how for instance the car charging facility at the University of Twente is optimized to ensure the grid hosting capacity, how the heat-pump control is organized in the village of Voerladegaard in Denmark

and how an overall set up energy system in the village of Przywidz is set up in Poland. Finally, the actual demonstration site ideas from Barubeda test site in India will be shown.

1. Introduction

In recent decades, the penetration of renewable energies, such as wind and solar, has increased in power systems worldwide. The primary challenge accompanying this high penetration of renewable energies is their volatility and intermittency. To mitigate the fluctuation in renewable power, demand flexibility can be integrated into power systems [1]. Demand flexibility is discussed across various sectors, including residential, industrial, agricultural, and commercial [2]. There are different power demands in the abovementioned sectors that can provide flexibility for power networks. Among them, electrical vehicles (EVs), Heat Pumps (HPs), Photovoltaic (PV) panels, and electrical batteries demonstrate particularly high potential.

In relation to EVs there has been a recent increase in the penetration, expected to become dominant in the next few years. Therefore, the flexibility potential of the mobility sector will play a crucial role in mitigating renewable power fluctuations [3]. EVs can be charged during periods of excess renewable power availability when electricity prices are low. Conversely, they can discharge power into the grid during periods of renewable power deficit corresponding to high electricity price hours.

The penetration of HPs is increasing in many areas, especially in regions without access to district heating or gas networks [4]. HPs can provide 3-5 times more heat energy than the electricity they consume. Their compressors can respond to demand response requests, adjusting power consumption in line with renewable power availability. In recent years, some research studies have focused on HP controllers to unlock heat-to-power flexibility. An Economic Model Predictive Controller (EMPC) has been designed for residential HPs to optimize flexibility in response to dynamic electricity prices [5]. This controller accounts for uncertainties related to weather forecasts from local weather stations. Additionally, a stochastic Model predictive control (MPC) is suggested to address electricity price uncertainties in various short-term electricity markets [6]. Many studies propose linking HPs with thermal storage to enhance flexibility potentials, with water tanks [7] and phase change material (PCM) storage [8].

When fossil fuel cars are phased out and replaced by EVs, power systems face several challenges such as voltage drops and power congestion due to the increased penetration of EVs [9]. However, if the charging and discharging operations of EVs are optimized, the power system can benefit from their substantial electrical storage capacity, effectively functioning as virtual power plants [10]. In the study [11], a bi-level coordination technique was applied to optimize the charging and discharging of EVs in residential areas to provide voltage regulation. Shared EVs and smart charging stations were suggested as practical solutions to mitigate congestion in distribution networks [12].

PV panels can supply portions of local power consumption, thereby reducing the burden on the local power grid and minimizing operational costs [13] and power losses [14] for the distribution network. Among these, rooftop photovoltaic sites play a key role in local demand supply [15]. Typically, PV panels meet demand during daytime hours. To address this limitation, PV panels are often connected to electrical batteries. In this way, a smart controller is proposed for the PV-battery system not only to fulfill local demand during nighttime hours but also to optimize the charging and discharging operations of the batteries based on distribution requirements [16]. Additionally, smart control is suggested to provide up and down voltage regulation [17].

2. Flexibility Provision from Demo Sites of H2020 Projects

In the paper, we will demonstrate various smart energy management systems including HPs, EVs, and PV-battery systems based on the two EU projects SERENE and SUSTENANCE, conducted across four demo sites in Denmark, the Netherlands, Poland, and India. Specifically, in the Netherlands, we address the EV smart charging facilities from the University of Twente to ensure grid hosting capacity. In Denmark, a flexible HP control is implemented in the village of Voerladegaard. In Poland, an overall flexible energy system setup is implemented in the village of Przywidz and in a housing association in Sopot. Finally, we will explain the actual flexibility provisions at the demonstration sites from the Barubeda, Borakhai, and Bombay test sites in India.

2.1. EV Flexibility in the Netherlands

The University of Twente Field Lab, commonly named *SlimPark*, meaning Smart Parking, is an EV charging station located at the University of Twente (UT). Figure 1 shows the actual *SlimPark* site at UT. It is a real-world laboratory of the Energy Management Research group of the UT, in which Energy Management algorithms are tested in practice with real users. It is therefore an essential bridge from theory to practice. It allows students and researchers to test and validate new concepts close to their office when theory is proven in simulation studies, but not yet ready for practice.

Figure 1. The EV charging station at the UT campus, i.e., SlimPark

The SlimPark Field Lab consists of the following components:
1. 9 3-phase 22kW (32A per phase) Mennekes Amtron Pro AC chargers.
2. 69 PV panels of 360W each, making in total 25 kW of rooftop solar panels.
3. 25kW PV inverter.
4. 30 kWh capacity with 20kW battery storage system.
5. All components are connected to a 3-phase grid connection with a 125 A per phase capacity.

All components are connected to a so called DEMKit system [18] for data gathering and for executing EV scheduling algorithms. DEMKit, short for Decentralized Energy Management toolkit, is a smart grid simulator and demo tool developed by the UT. It is used for thorough analysis and operational control of smart grids via simulations. With its agent-based design, it forecasts and plans energy use using local data.
Actual data from the charging stations, PV inverter, battery, and grid meter can be brought in via a Modbus TCP interface. The charging stations are managed through the open-source charge point operator back-end, SteVe which allows retrieval of precise arrival and departure times, energy charged, and user information. This data can then be utilized to enhance control algorithms or experiment with various strategies within the DEMKit model. Figure 2 explains the schematic diagram of data and control flow in the SlimPark site.

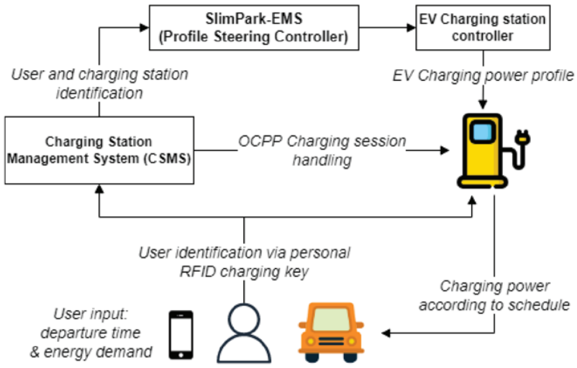


Figure 2. SlimPark demonstrator data and control flow schematic

Figure 3 investigates the added value of smart EV charging control and the implementation of a battery storage system in this demonstrator. Based on this simulation, spanning a work week, it is evident that there is significant potential for smart charging by synchronizing charging with local energy production through control. This will benefit the self-sufficiency of the parking lot, reduce carbon emissions, and significantly contribute to grid load minimization. The added value of a battery is very limited. However, the latter is included in the demonstrator for experimental purposes.

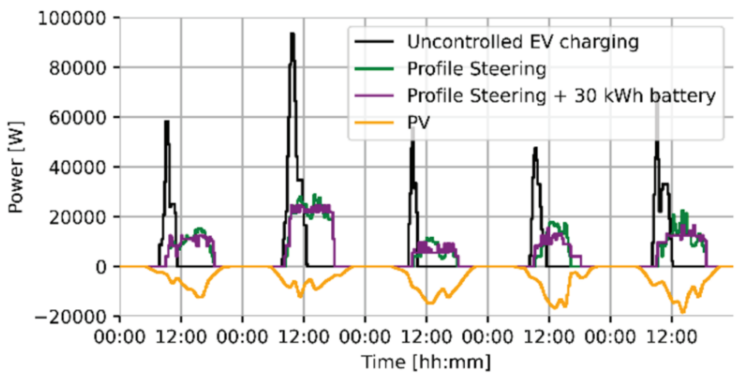


Figure 3. Example of simulation results for unlocking demand flexibility in the SlimPark site

2.2. HP Flexibility in Denmark

The Danish demo sites are located in Voerladegaard and Dorup villages, Skanderborg Municipality. The objectives of the demo sites are to remove the natural gas heating systems of individual residential buildings and replace them with HPs with smart salt PCM heat storage and PV systems. To achieve these aims, the following implementations are carried out on the demonstration sites.

- **Demo Cases in Voerladegaard and Dorup Village**

The Danish demonstration site for the SUSTENANCE project consists of 20 households with the following configurations:
(1) 20 homes have HPs.
(2) 6 different HP brands, sizes from 7 to 16kW.
(3) PCM storage capacities range from 200 – 1.500 liters.
(4) 10 homes have PV installed.
(5) 7 homes have an EV.

Figure 4 shows the HP and thermal storage in an individual houses of the demo site.

Figure 4. Installed HPs and thermal storage on the Danish demo site

Figure 5 illustrates a PI diagram of the HP controller in the Danish demo site. Based on the control diagram, the controller schedules the operation of the heating system in response to electricity prices. Assuming a strong correlation between electricity prices and renewable power availability, it optimizes the heat consumption to align with renewable power generation.

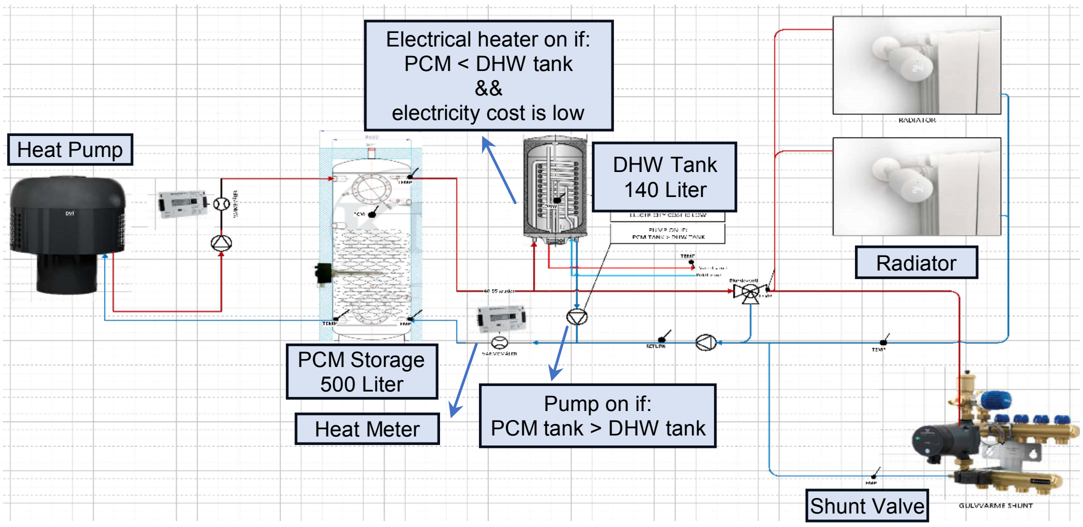


Figure 5. PI diagram of the HP controller in the Danish demonstration site

- **Integration of RES Community Systems into Power Grids**

At the same time, work is done to minimize bottleneck problems for the local power grid system caused by PV power production and power consumption for the HPs. In addition, cost-effective business models for heating individual residential buildings from integrated HPs with heat storage and PV systems are developed. The demonstration site can be called a *virtual smart PV micro-grid for energy communities*, where PV produced from individual PV systems in principal can be exchanged between individual residential buildings including *exporting* PV power to residential buildings with no PV system. Figure 6 illustrates the simulation results of the integration of the RES community systems into the power grid.

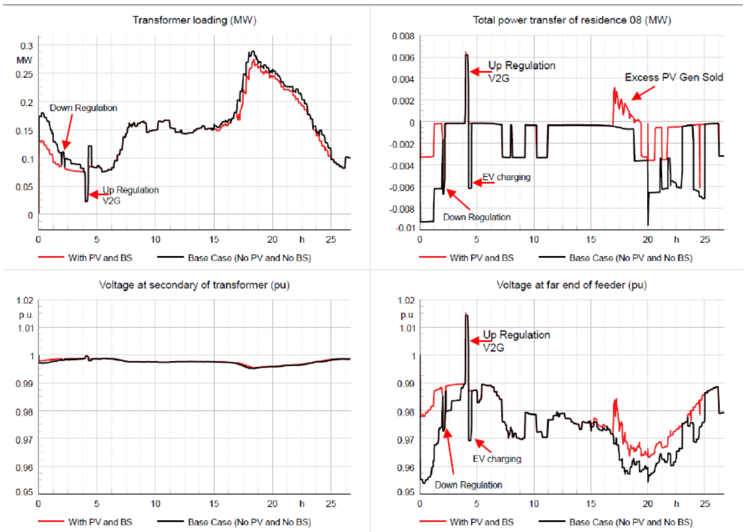


Figure 6. Simulation results on impacts from and integration of RES community systems into the power grid

2.3. Energy System Flexibility in Poland

The demonstration activities in Poland focus on the installation, demonstration, and testing of technologies for local electricity and heat production, EVs, energy storage and management for energy efficiency, and an increase in the share of local RES, visibility, and flexibility of the power grid. To achieve these aims, the following demonstrations are installed.

- **Smart Energy System in a Housing Association**

As the demonstration site for the SUSTENANCE project, in Poland, a residential building is chosen for the demonstration site in Sopot. The building has the utilities of water, gas, power, sewage, heat, and telecom. The energy consumption of the demo case is measured by installed meters for the living lab studies.

- **Local Energy Production, Storage and Management**

To unleash the heat-to-power flexibility, a GSJ 46EVI air HP is installed at the demo site in Sopot. Also, the main pipeline and water tanks were installed. Two tanks with a capacity of 150 m^3 each will be used as thermal storage. Figure 7 shows the HP and the water tank in the Polish pilot site.

Figure 7. DHW (Domestic Hot Water) tanks and GSJ 46EVI HP in the Polish demonstration site

- **Energy storage and EV charging stations**

In the SERENE project, the Polish demo sites include Arena Przywidz and the primary school, Szkoła Podstawowa im. Unii Europejskiej w Przywidzu, located at the heart of Przywidz, which are equipped with 39.99 kWp and 26.04 kWp photovoltaic systems.

Within the SERENE project, the energy storage unit in fluid-flow technology was added to the Arena's power system. It is a storage of 20 kW of maximal power and 96 kWh of capacity, everything is located in the container standing near the building. Within the project also 3 chargers are installed – one DC charger of 25 kW and two AC ones of 22 kW each. The DC charger is used by the electric bus which is part of the electric rural bus line, with a bus terminal near Arena Przywidz. All those devices will be connected by the Energy Management System (EMS) that will manage the energy storage and the charging of the cars. The EMS will provide energy balancing with the aim of minimizing energy costs. Figure 8 shows the Arena Przywidz as the dome site and the electric bus that is used regularly around Przywidz.

Figure 8. Arena Przywidz as the Polish demo site with the electric bus for local citizens

In the demonstration sites, many simulation studies are conducted to examine the impacts of the sizable demands on the flexible operation of the power grids. As an example, Figure 9 explains that the application of ESS paired with PV can result in significant energy cost reduction.

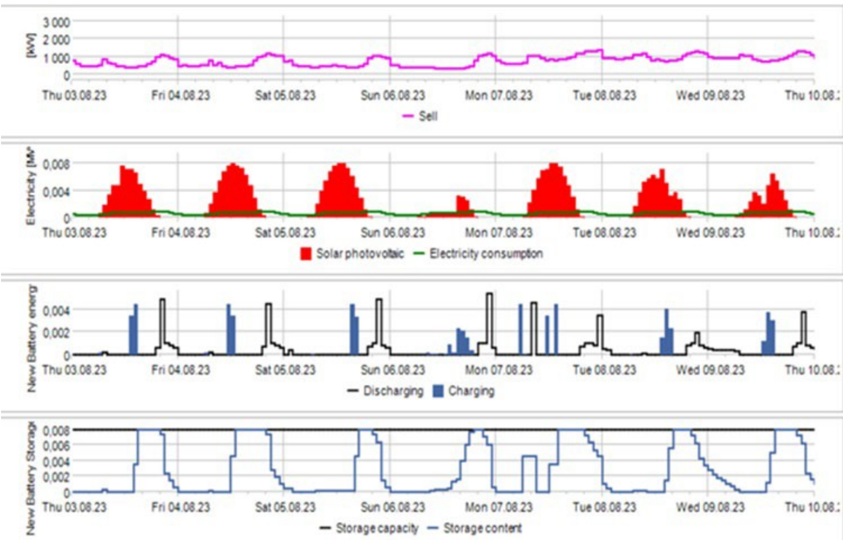


Figure 9. Example of Residential PV+ESS simulation

2.4. Energy System Flexibility in India

The main objective of the Indian demonstrations is to achieve customer-driven carbon-neutral local energy communities for remote off-grid villages, weak grid-connected remote communities, and district/suburban grid-connected communities. The goal of sustainable energy systems can be achieved by addressing critical verticals of energy, water, heating

and cooling, irrigation, cooking, and transportation through an optimized cross-coupled integrated energy carrier approach. As a part of the SUSTENANCE project, the above solutions will be deployed for demonstration at three uniquely different local energy systems focusing on the following pilots in India:
(1) Barubeda Village, Jharkhand, as an off-grid local energy system.
(2) Borakhai Village, Assam, as a weak grid-connected system.
(3) IIT Bombay campus, Mumbai, Maharashtra, as a grid-connected integrated smart building system.
Figure 10 shows demand flexibility structure in one of the Indian demonstrators. As can be seen, in the grid-connected area, smart building provide flexibility for upstream networks. In the DC microgrids, PV panels, small wind turbines, domestic water supply, and EV charging stations are the key components of the demonstration sites.

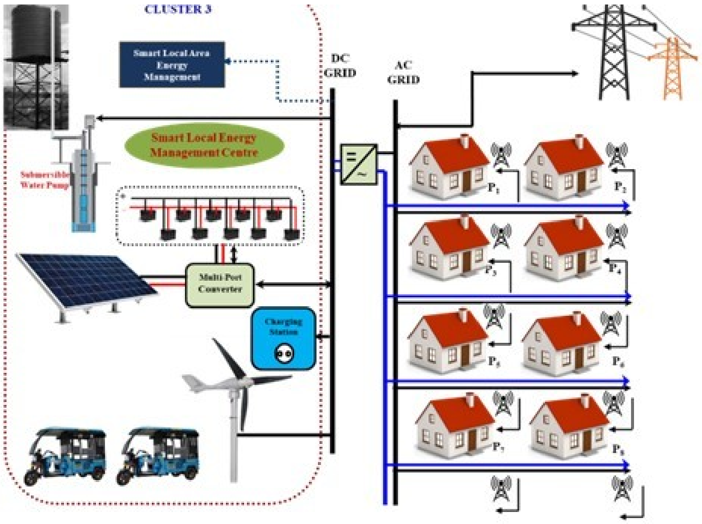


Figure 10. Key components of Indian demonstrations site for flexible energy management system

In the Indian demonstration sites several systems are initiated as prototypes which are detailed in the following.

- **Biogas-based Power Generator and Biogas-based Cooking**

The biogas plant has a 100 m^3 capacity with a 12-kW generating facility with the primary product being biogas supply for cooking applications, and the secondary product being electricity generation. The raw material for the biogas plant will be sourced locally from the village and the same has been discussed and agreed with the local Village Energy Committee.

- **Low-Speed Hybrid Solar PV-Wind Power Plant**

Deployment of low-speed hybrid solar-PV wind is a part of generation deployment at the Borakhai site. The hybrid system will form part of the total generation system which includes 34 kW solar PV along with a battery storage system of around 290 kWhr. There are two sites physically apart from each other in Silchar, and the low-speed hybrid system is a part of the generation system at the ‘off-grid’ cluster.

- **Domestic Water Supply System**

Geoinformatics/GIS-based approaches were applied in the selection of optimized locations to install the PV water pumping system for cost-effective and energy-efficient operation. Water quality tests are initiated for the Borakhai site. Based on the groundwater level mapping conducted for Barubeda village, it is inferred that the exact groundwater level at the preferred location for the installation set-up can be measured only through the actual borewell digging.

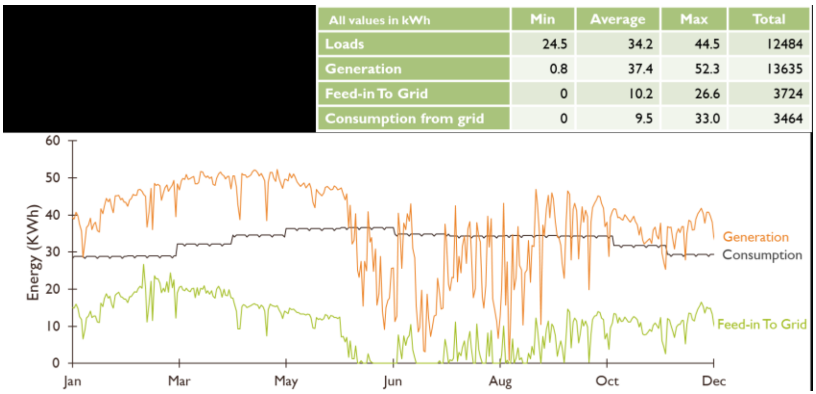
- **Multi-Utility Heat Pump-Based Community Cooling, Heating and Drying**

Design and analysis of the Multi-Utility Heat Pump (MUHP) are developed for milk chilling, water chilling for precooling of fruits and vegetables, and warm air for drying agro produce. Milk chilling from 36^{oC} to 6^{oC}, water chilling from 30^{oC} to 15^{oC,} and heating ambient air up to 45^{oC} and/or water heating from 25^{oC} to 55^{oC}. Figure 11 shows the installed MUHP in the pilot site.

Figure 11. Multi-utility heat pump unit at the Indian demonstration site

- **Smart Electrical Building Systems**

The smart electric building is developed at the campus of IIT Bombay. The building is equipped with a battery storage-enabled solar PV system. The net-zero electricity consumption of the building has been demonstrated in Figure 12 and further measurements are being taken from the building.



All values in kWh	Min	Average	Max	Total
Loads	24.5	34.2	44.5	12484
Generation	0.8	37.4	52.3	13635
Feed-in To Grid	0	10.2	26.6	3724
Consumption from grid	0	9.5	33.0	3464

Figure 12. Net zero electricity of the smart electrical building on the campus of IIT Bombay

4. Conclusion

In this paper, we discussed different demonstration sites in EU countries, including the Netherlands, Denmark, Poland, and India as the Asian partner. The demonstration sites belong to two H2020 projects SUSTENANCE and SERENE which aim to integrate the flexibility of sizable demands, e.g., HP, EVs, and batteries into smart energy systems, alongside increasing the penetration of RES within energy systems.

The performance of demonstration sites shows that power and heat demand flexibility are workable solutions to provide support for local energy systems, e.g., voltage regulation and load balance. In addition, it can increase the penetration of renewable energy within local energy communities. The results are not standing only for interconnected grids but also for off-grid remote areas. Herby, distributed energy systems benefit from cost-effective and reliable operation, while remote microgrids supply the local demands using locally available materials and resources.

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