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D4.6 Report on smart grid improvements

WP4, Task 4.3 (Subtask 4.3.2)

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife	
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**	
Project Duration	1st December 2016 – 30th November 2021 (60 Months)	
Deliverable	D4.6 Report on smart grid improvements	
Diss. Level	PU	
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Due date	30/11/2019	
Work Package	WP4	
Lead beneficiary	HEN	
Contributing beneficiary(ies)	VTT	
Task description	**Task 4.3: Smart Energy Supply and Demand [HEN] (HEL, FVH, VTT, FOU, CAR)** The task focuses on demonstrating technical integration of RES and storages in the district heating and cooling network with power production. The focus is in optimising the production and reduction of system level CO_2 emissions. Important part of the optimisation is the use of waste energy sources. The task also focuses on system level demand side management and optimisation of the performance including reactive power control and balancing. **Subtask 4.3.2**: Smart grid, Energy storage strategies deployment and renewables. Led by HEN, implementation of solar power plant and reactive power compensation by solar power plants.	

Date	Version	Author	Comment
21/04/2017	0.1	Kristiina Siilin (HEN)	First draft of the structure
02/06/2017	0.2	Atte Löf (VTT)	Drafting the contents of the Kivikko part
16/08/2017	0.3	Antti Alahäivälä (VTT)	Writing the review of Kivikko, results and future prospects
18/09/2017	0.4	Kristiina Siilin (HEN)	Commenting the Kivikko review
21/09/2017	0.5	Kristiina Siilin (HEN)	Writing Korkeasaari review
04/10/2017	0.6	Krista Jaatinen (HEN)	Writing the review of Korkeasaari
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27/11/2017	1.0	CAR	Alignment of contents and final review
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24/11/2019	1.5	Timo Ruohomäki (FVH)	Reviewed with minor comments
26/11/2019	1.6	Suvi Takala (HEN)	Final modifications based on the project internal review by FVH.

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Abbreviations and Acronyms

Acronym	Description
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
DSO	Distribution system operator
HSV	Helen Sähköverkko Oy (Helen Electricity Network Ltd.)
PPA	Power Purchase Agreement
PV	Photovoltaic
RES	Renewable Energy Sources

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1. Executive Summary

This deliverable focuses on solar power, demonstrating the technical capabilities of solar power plants (reactive power compensation test) as well as on the business models to integrate more solar power to the energy system. The chapter 3 focuses on technical demonstration of reactive power compensation with the inverter of a solar power plant and chapter 4 describes business models of solar power. The chapter 3 takes into account also the citizen engagement aspects.

The deliverable focuses on already existing Kivikko PV plant, which prodived the demo site for reactive power compensation test and to the implementation of new solar power plant in Helsinki to the roof of Messukeskus, Covention and Expo Centre in Pasila. Kivikko solar power plant was built in 2016 on the rooftop of Arctic Sport Centre. The nominal capacity of Kivikko PV plant is 850 kWp. The Kivikko solar plant has operated reliably and without interruption for the active power production of the plant. The Arctic Sport Centre has large cooling demand since it provides skiing opportunities indoors. The constant cooling produces reactive power, which is billed by the distribution system operator.

The solar power plant was demonstrated to be capable of compensating reactive power with its inverters. At first, the inverter of the solar power plant was set to compensate the reactive power produced by the Arctic Centre and hence reduce its yearly reactive power payments for distribution system operator (DSO), Helen Electricity Network Ltd. The tests showed that the inverter is capable to compensate reactive power during active power production. The slight decrease in measurements of reactive power was observed based on the collected data and hence the concept works although the economic benefit remains small.

The second test was done during nighttime, without solar power production and with the aim to provide reactive power compensation for the local DSO. The reactive power was successfully compensated also during nighttime. Although technically possible, no business potential exists for such an operation since no local reactive power market of DSO currently exists. In addition, there are no issues with reactive power and voltage control in the distribution network of Kivikko area. Furthermore, it can be also argued whether compensating reactive power with solar plant's inverters is economically viable, since the compensation will affect the lifetime of inverters. The compensation was proven to be technically possible with Kivikko PV. However, since there is currently no clear business opportunity to continue reactive power compensation in this location, the compensation was not continued after the testing phases.

The chapter 4 of this deliverable focuses on implementation and business opportunities of solar power plants. The chapter describes the planned implementation of solar power plant in Korkeasaari Zoo, which was eventually cancelled and replaced with another PV panel concept in another location in Helsinki. At first stage, the idea with Korkeasari Zoo PV was to activate the visitors and to engage them to donate

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money in order to build solar plant. Different approaches were used and it was noticed that it is not easy to get the citizens involved. Helen had planned workshop series to co-create the concept with citizens but eventually, the carefully planned workshops did not work out. Other business model options were considered after the low success of the workshops, but in the end the implementation of solar power plant to Korkeasaari Zoo was cancelled. The main reasons for the cancellations of the original plans were 1) organizational change in the Helsinki City (Koreasaari was formerly a part of the city organization but in the beginning of 2018 it became a foundation run entity), 2) electricity system issues (changes would have been required to the electricity system if more solar power was installed) and 3) the lack of interest from public to the initial financing model.

However, Helen replaced the mySMARTLife action of Korkeasaari Zoo PV with another PV power plant (600 kWp) to be implemented to the rooftop of Messukeskus, Convention and Expo Centre in Pasila, Helsinki. The business model of the new solar power plant, Messukeskus PV, is based on the business model of already existing designated solar power plants of Helen, Kivikko PV and Suvilahti PV. In the concept of designated panels, Helen's customers can rent a PV from the power plant and can participate in solar energy production without purchasing a solar panel on their own roof. Designated solar panles give an easy access to renewable energy production. Helen compensates the production of the rented solar panel(s) in the electricity bill of the customer. Helen's customers have showed a great interest for the designated solar panels, since in spring 2019, both of the existing designated panels were sold out. Therefore, the demand for a third designated solar panel was high from the customers' side.

The implementation of the new Messukeskus PV power plant started in the end of May 2019 and the implementation is done in two phases. The first phase was finished in the end of August 2019 with 1589 panels (500 kWp) installed to the rooftop. The installation continued with the second phase and ca 300 panels (100 kWp). The implementation of the new PV plant will be finalized by the end of 2019. Customers can already reserve a PV from the new power plant. In the end of October 2019, already over 1200 panels were reserved, and therefore the business model has been successful.

The interest for PV production has increased and is increasing in Finland. The business model of designated solar panels is targeted for environmentally conscious persons willing to also invest some money to participate in local solar energy production. The business model of designated solar power plants is replicable especially in cities with growing interest in solar energy production and environmental friendliness. The business model has been a success in Helsinki, but this does not necessarily guarantee that the same kind of success could be reached in other regions or in other countries. Therefore, the successful implementation of the business model needs local knowledge on the customer segments and their needs as well as successful marketing.

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2. Introduction

2.1 Purpose and target group

This deliverable describes technical possibilities as well as business concepts of solar power plants. Firstly, the examination of reactive power compensation with a solar power plant is carried out by investigating the technical readiness as well as the business potential of such operation. The deliverable points out the economic and business model challenges related to reactive power compensation with PV panels. Secondly, a crowd-funding concept, which was targeted for Korkeasaari Zoo is presented and the reasons for the replacement of the action with new plans are discussed. Thirdly, the deliverable describes the concept of designated solar panels, which has been a key to implement more large-scale solar energy production in Helsinki and engage citizens to solar energy production.

The replication potential lies within similar ecosystems, such as energy companies or cities planning to purchase or expand solar power plants. On the other hand, the deliverable describes the experiences and success that Helen has had with the implementations of designated solar panels in Helsinki. This deliverable will hence provide information for players in different ecosystems who are running RES business and attracting large crowds.

2.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
HEN	Overall content to sections 1, 2, 4, 5
VTT	Writing the contents of the Kivikko review in chapter 3 based on the information provided by Helen (data and system description)
FVH	Peer review

2.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities and deliverables developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

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Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D1.9	"Innovative business models. Making things happen": This deliverable describes the business model of implemented new solar power plant, Messukeskus PV in Pasila, Helsinki (the rooftop of Messukeskus, Convention and Expo Centre).
D4.1	"Baseline report of Helsinki demonstration area": This deliverable provides the overall description of the baseline
D4.7	"Report on monitoring and control concepts and improvements": This deliverable discusses the business model possibilities of reactive power compensation.

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3. Reactive power compensation demonstration with a solar power plant

3.1 Compensation requirements and strategies with solar power plants

Reactive power is an inherent characteristic of a conventional electrical grid. In order for the grid to function properly, reactive power levels need to be managed. This management is also called reactive power compensation or var compensation (Dixon et al. 2005). The compensation reduces losses and congestion in the grid, as it removes unnecessary reactive power flows and thus, the lines can deliver mainly active power instead of reactive. On the other hand, reactive power is closely connected to the grid voltage, which tends to increase with excess reactive power in the system and decrease when it is consumed. Reactive power is consumed in inductive components, such as in transformer, induction motors, and rectifiers. Instead, capacitive components, such as low-loaded cables, inject reactive power to the grid. In the past, the customer devices were usually consuming reactive power but nowadays the devices are also producing reactive power, which in addition to cabled network, has affected the reactive power compensation needs of the DSOs. For example, nowadays lighting devices (LEDs) as well as customer electronics using capacitors are examples of capacitive. In the distribution network of Helen Electricity Network (DSO in Helsinki), the decline of reactive power consumption has been noticed. The changed reactive power characteristics in the distribution network of Helsinki have been reported in Pihkala et al. 2019.

Cooling load is an example of a load that consumes reactive power. Cooling load is also the reason why the considered location, Kivikko, is of interest for compensation studies: there lies an indoor skiing center requiring cooling, and thus reactive power, throughout a year. On the other hand, Kivikko is located in an urban distribution network where a major part of the grid has been cabled. Due to the cabling and its capacitive nature, the grid may produce reactive power during low loading periods, such as at nighttime.

Distribution system operators (DSOs) are obligated by the law to supply their customers with electricity with certain quality (Lakervi & Partanen 2009). The quality requirements are set in standard SFS-EN 50160 where, for example, the required voltage levels are defined. This is one reason for a DSO to pay attention to the reactive power compensation. Furthermore, proper voltage levels are closely connected to the economical (e.g. low losses) and technical (e.g. electrical insulation of devices) functioning of the grid, which is another reason for the reactive power management. Conventional devices for the reactive power compensation are capacitor banks and reactors (Vaisanen 2012). They are sized and located to the grid to obtain optimal compensation. Naturally, reactive power compensation causes costs to the DSOs, which are charged from customers with distribution tariffs or separate reactive power payments.

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Solar power plants, or photovoltaic (PV), are typically considered as a form of distributed generation, since they are located and are connected to a distribution grid. From the reactive power compensation viewpoint, the structure of plants and their distributed nature have two consequences. Firstly, PV causes power flow toward upstream voltage levels, which may further cause unwanted voltage rise in the grid. This changes the nature of voltage level management in the distribution grid compared to the conventional case where power flows are from high voltage levels to low. Secondly, solar panels are connected to the grid through an inverter, which can provide several functionalities for the grid management, such as the control of supplied active and reactive power. For example, droop control can be applied to adjust the active and reactive power output of a plant in proportional to the frequency and voltage level of the grid (Yang et al. 2016). In addition to the droop, PV system can be controlled to operate with fixed power factor or to inject or consume fixed reactive power (Braun et al. 2009). With these functionalities, reactive power levels and the voltage rise issues can be managed and mitigated.

Even though PV inverter enable the compensation of reactive power, the plant owner may not have motivation to do so. Currently in Finland, there is no possibility to sell such an ancillary service. Compensation may become topical if the plant owner has also reactive power consumption or injection at the site where the plant locates. The reactive power exchange with the grid can be reduced and thus, some savings in the reactive power payments are possible. However, it is not quite clear whether the compensation is economically justified from the plant owner’s point of view. The control of inverter to consume or inject reactive power increases thermal and electrical stress on the component of the device, which can have negative effect on the inverter lifetime. Further, the control can cause additional losses and decrease the inverter efficiency (Flicker & Gonzalez 2015).

3.2 Demonstration with Kivikko solar power plant

3.2.1 Aim of the demonstration

The demonstration aims to investigate the possibilities to employ a solar power plant in reactive power compensation in order to improve its economical efficiency. Of particular interest is to find a feasible approach, which can be tested in Kivikko. Different possible approaches are discussed and two are selected for further analysis in this demonstration. One selected compensation strategy is based on the injection of fixed reactive power to the grid. Another tests reactive power consumption from the grid at nighttime. The following subchapters will describe the studied system, the compensation strategies, and the demonstration results.

3.2.2 System description

Helen Ltd. has built a new solar power plant in the Helsinki district of Kivikko in April 2016. Almost 3000 panels covers an area of about one hectare on the roof of the Kivikko Arctic Sport Center, which is owned by the City of Helsinki. The nominal power of the solar power plant is 850 kW and the size of its inverter is

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1 MW (2 x 500 kW). The inverter is manufactured by ABB and its model is PVS800-MWS (also called the megawatt station). The output of the inverter is connected to the nearby 20 kV substation via a 1000 kVA step-up transformer. Kivikko solar power plant is shown in Figure 1 and ABB's PVS800 inverter is in Figure 2.

Figure 1: Solar power plant in the Helsinki district of Kivikko. Photo: Helen Ltd

Figure 2: ABB's PVS800 inverter (ABB 2019)

Hourly production data from the solar power plant is available at the Helen Ltd. website (Helen 2019a) and the production is depicted in Figure 3 for a time span of 11.4.2016–31.12.2016. The output of the power plant exceeds 800 kW and the annual output was approximately 700 MWh during its first operational year.

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The solar power plant is connected to the same transformer substation with Kivikko Arctic Sport Center and the generated energy is used to cover part of the consumption in the Arctic Sport Center. The sport center also consumes reactive power because of the cooling devices installed in the building. The inverter of the solar power plant has an ability to provide reactive power compensation. Therefore, the reactive power supply from the grid could be decreased and the costs for reactive power consumption can be reduced. Active power and reactive power consumption during a time period of 11.4.2016–31.12.2016 in the Arctic Sport Center are presented in Figure 4 and Figure 5, respectively. One can note that the reactive power consumption is slightly higher in summer compared to the winter, which is due to the cooling load.

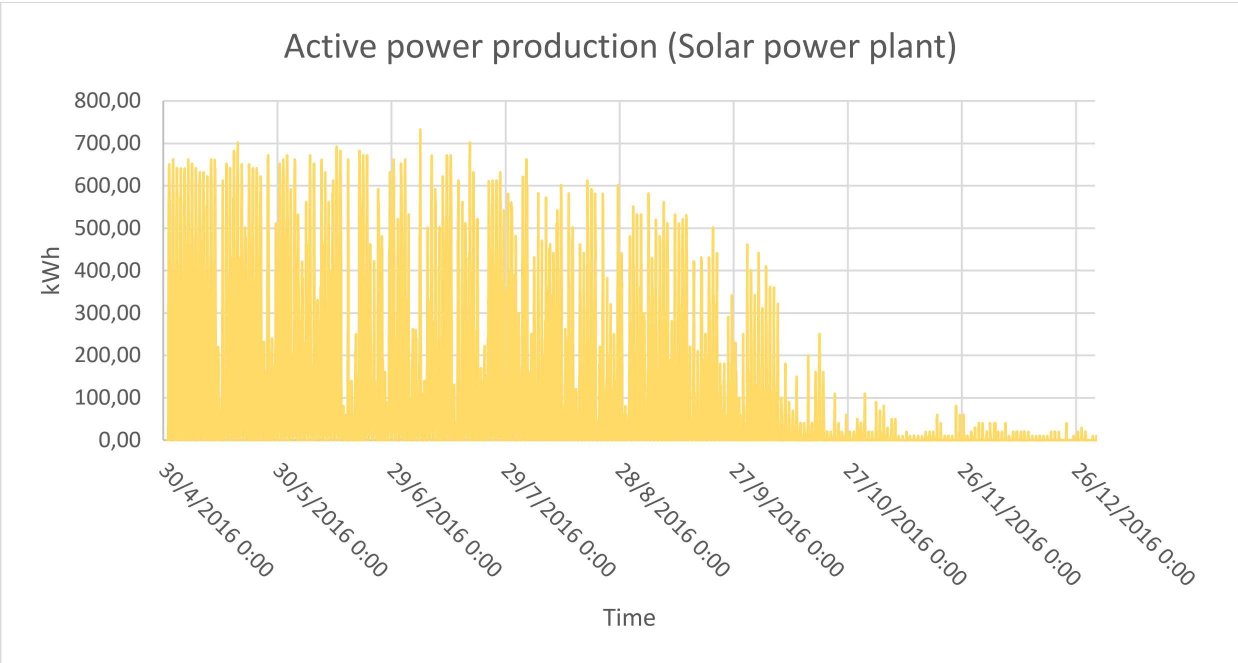

Figure 3: Hourly production data of Kivikko solar power plant (Helen 2019a)

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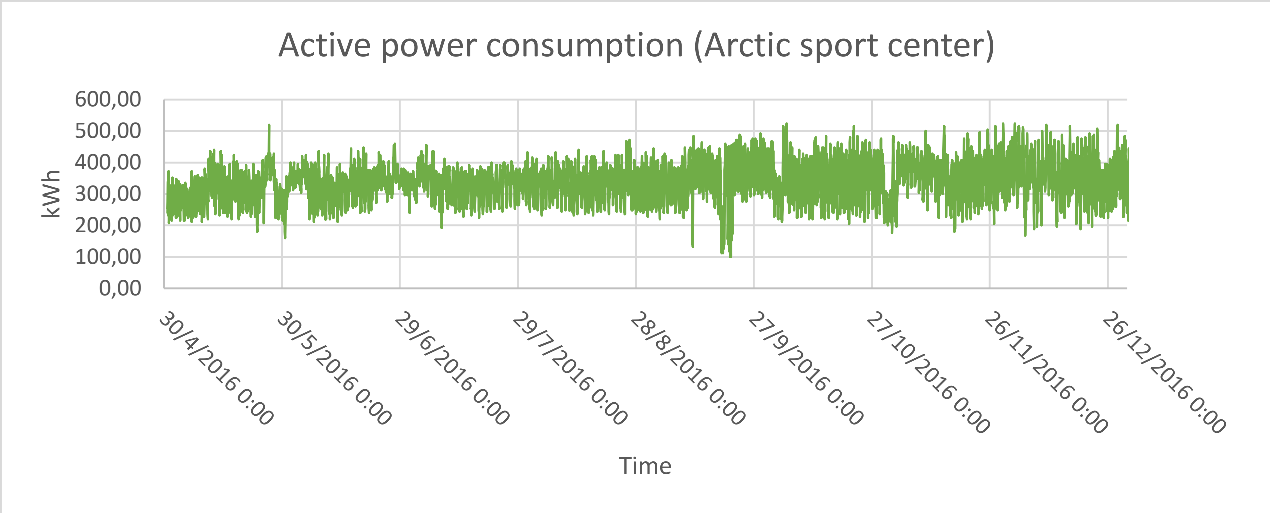

Figure 4: Kivikko Arctic Sport Center active power consumption without PV generation

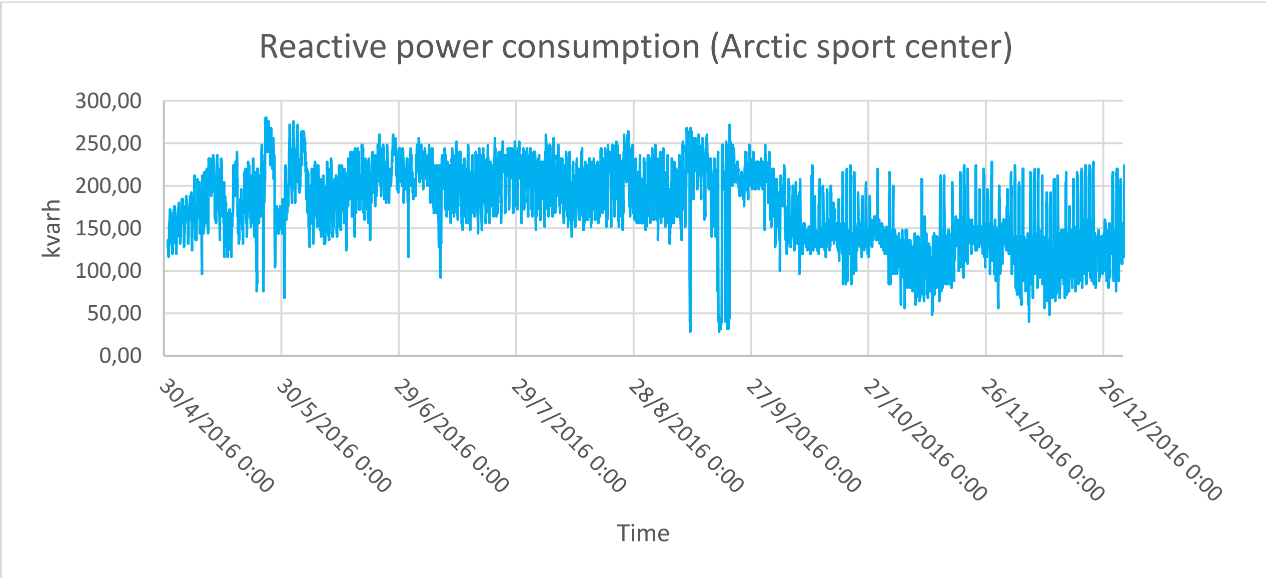

Figure 5: Kivikko Arctic Sport Center reactive power consumption without reactive power compensation

3.2.3 Applicability of Kivikko power plant on reactive power compensation

There are several options to control the reactive power supply with ABB's PVS800-MWS inverter. A first option is to set fixed parameter value, e.g., power factor or constant reactive power value, to control the reactive power production. The operation is possible either when the plant generates active power or with some modifications also continuously through a day, meaning that the inverter is on and provides compensation even though the panels are not producing power. A second and more dynamic option is to build a software, which sets the inverter to control the reactive power production based on measurements from the inverter and the sport center. A third option is to connect the inverter to already existing operation

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control system, e.g., SCADA, which gives control commands to the inverter for reactive power control. All the aforementioned options enable both reactive power consumption and injection. One can also note that the inverter rating (2x500 kW) exceeds the maximum output of panels (850 kWp). That is, the inverter can provide compensation without starting to curtail active power generation.

3.2.4 Reactive power compensation demonstration

The main motivation to compensate reactive power with Kivikko solar power plant is to reduce reactive power payment at the site. This is currently the possibility to obtain monetary benefit from the compensation. Kivikko is located in the distribution grid of Helen Electricity Network Ltd. (HSV) so their reactive power tariffs apply. In 2017, the price of the reactive power consumption was 2.47 €/kvar and the billed consumption is the highest measured monthly reactive power consumption value minus 40% of the highest measured monthly active power or at least 50 kvar (HSV 2017). That is, HSV provides a certain amount of reactive power without cost. In 2017, the price of injected reactive power was the same as consumed but the billed power was defined differently.

Maximum reactive power consumption of the Arctic sport center for May and each summer month in 2017 (May-August) is illustrated in Figure 6. As seen from the figure, the maximum reactive power consumption in different summer months is usually in the early morning. Therefore, it is suitable to control the reactive power production with constant reactive power value instead of power factor value. The control with fixed power factor would provide only a little compensation in the mornings when the active power generation is low.

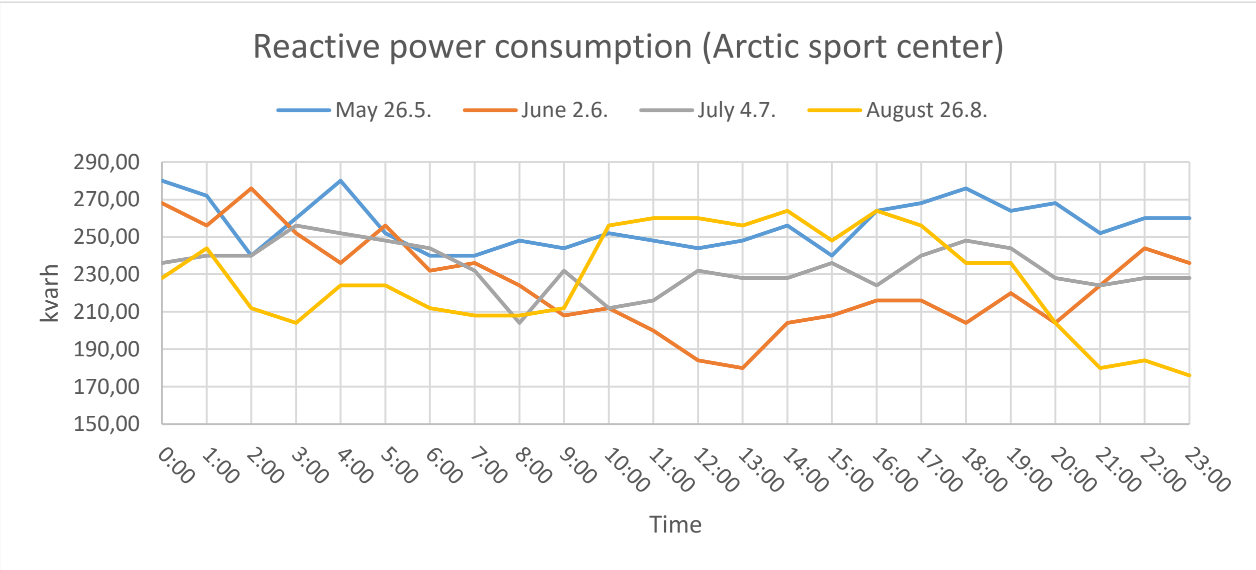

Figure 6: Maximum reactive power consumption in different months in year 2017

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For the demonstration, the solar power plant is set to inject a reactive power of 30 kvar when the plant is also generating active power. Note that the inverter is overrated and thus the plant could produce more than 30 kvar without limiting the active power generation. However, the used value is selected so that the injection of the reactive power would not exceed the consumption of the skiing centre as over compensation want to be avoided. As mentioned, the inverter is also able to provide reactive power compensation continuously without active power generation. This approach would probably be more effective. The demonstration of daytime reactive power injection of 30 kvar was performed during the time period from 11.5.2017 to 19.6.2017.

3.2.5 Results from demonstration

The results of the demonstration are presented in this section. Firstly, Figure 7 shows the active power generation of the solar power plant and the active power consumption of the Arctic Sport Center from the measurement period. The consumption is approximately 300 kW indicating somewhat similar consumption as was measured in the previous year (see Figure 4). During most of the days, the PV generation reaches high levels, exceeding the local consumption greatly.

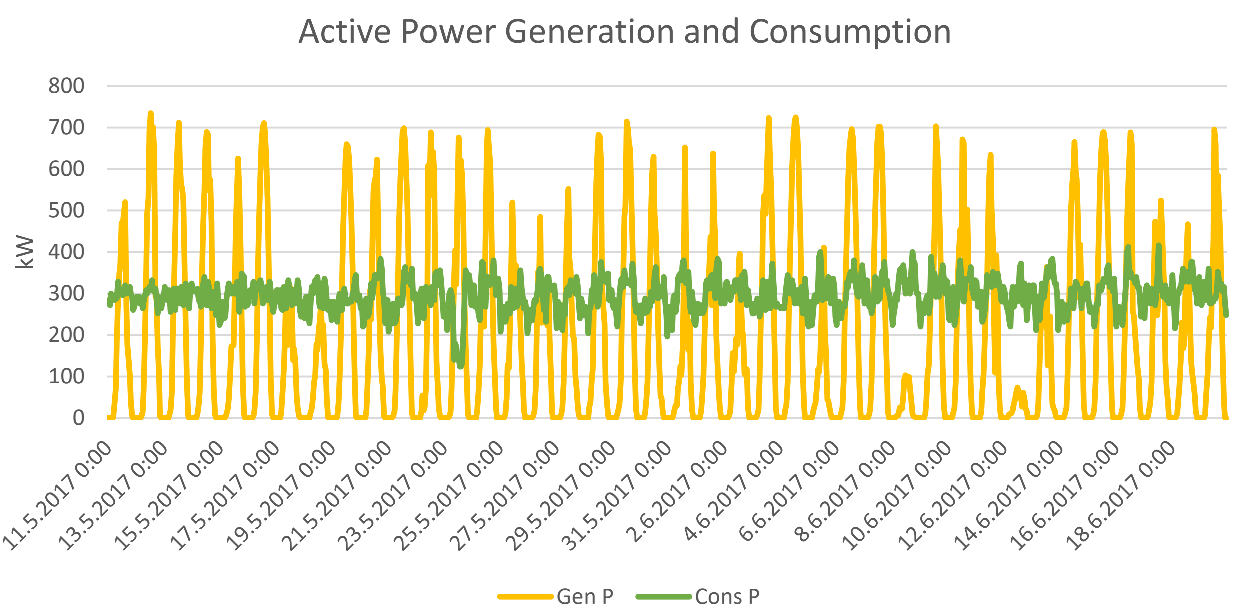

Figure 7: Solar power generation (Gen P) and the active power consumption of the sport center (Cons P) during the demonstration period. The values are hourly means

Figure 8 depicts the active and reactive power production of the PV plant for the first week of the demonstration period. The injected reactive power does not reach the set 30 kvar, which is likely due to the reactive power consumption of the transformer of the power plant. The measurement point is on the

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grid-side of the transformer and therefore, precise reactive power production of the plant cannot be seen in the results. The consumption of the transformer increases as a function of the PV active power feed-in, which is why the reactive power injection drops at noon. Nevertheless, the injection is nearly 30 kvar when the active power generation is low, for example, in the mornings and evenings. It should also be noted that the results are hourly mean values and that the plant provides compensation only when it is on. Therefore, if the plant switches on or off during an hour, the hourly reactive power production may seem low. This can be observed during mornings and evenings.

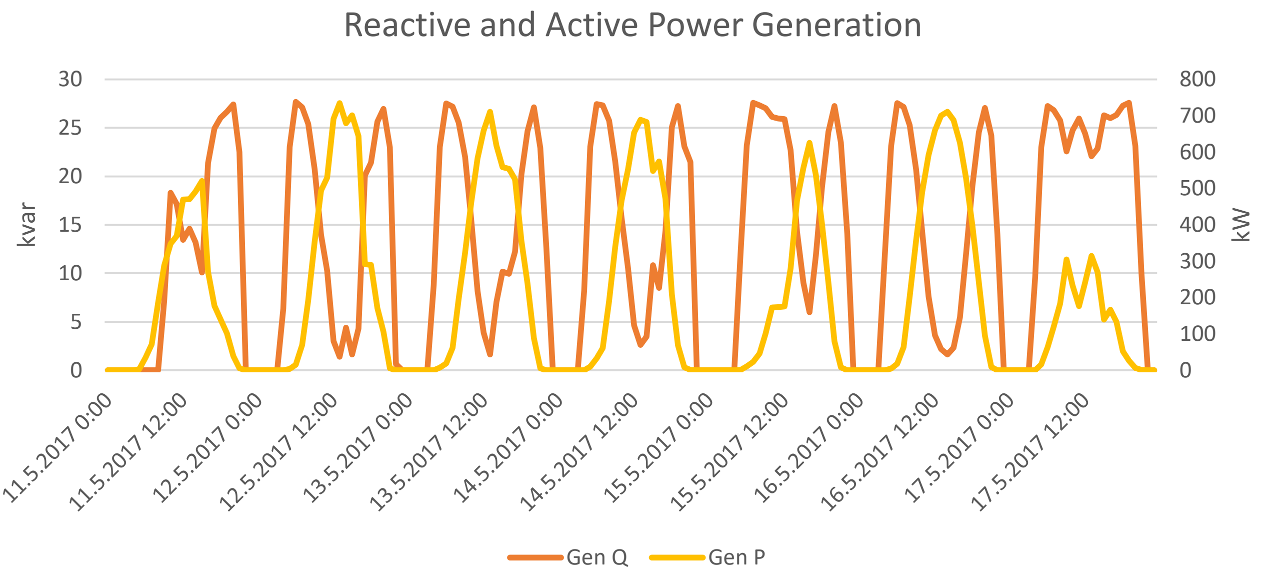

Figure 8: Reactive (Gen Q) and active power (Gen P) production of the solar power plant zoomed to the first week of the demonstration period

The reactive power consumption of the Arctic Sport Center is present in Figure 9 so that the blue line shows the consumption without the compensation and the grey line when the injection of the PV plant has been subtracted from the consumption. Minor yet visible reduction in the consumption is achieved with the compensation.

Lastly, the influence of the compensation on the billed reactive power is evaluated in Table 3. It can be seen that the solar power plant reduced the maximum active power consumption slightly from 416 kW to 390 kW. The consumption (net consumption) is obtained by subtracting the generation from the consumption of the sport center. When the compensation provided by the power plant is considered, the maximum reactive power consumption of the site decreases from 211 kvar to 208 kvar. If the billed amount of reactive power is considered, the installation of the solar power plant actually increases the payment due to the reduction in the maximum active power consumption. That is because the active

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power affects the amount of free reactive power the DSO allows (see Section 3.2.4). However, if the power plant provides compensation, the amount of billed reactive power decreases from 55 kvar to 52 kvar. Thus, a minor reduction in the reactive power payment can be achieved with the compensation.

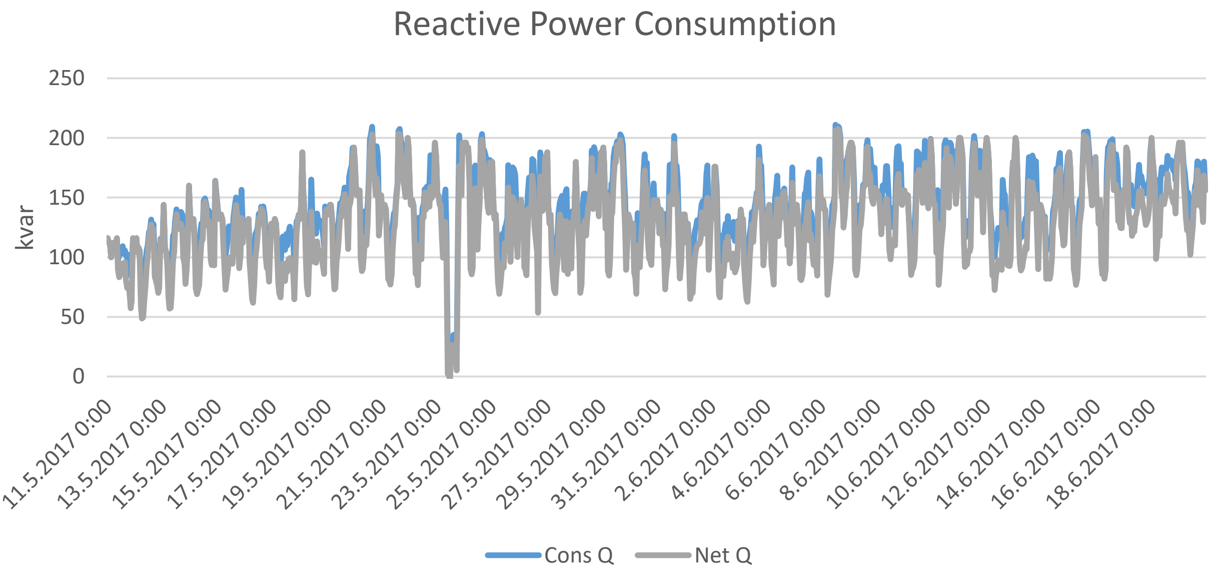

Figure 9: Reactive power consumption of the arctic center with (Cons Q) and without (Net Q) the compensation

Table 3: Maximum active and reactive power consumptions and the amount of billed reactive power from the demonstration period are presented in the table. The values are evaluated for the cases without active and reactive power generation (No Solar Generation), with active power generation but without compensation, and with active power generation and with compensation

	Unit	No Solar Generation	Solar without Compensation	Solar with Compensation
Max Active Power Consumption	[kW]	416	390	390
Max Reactive Power Consumption	[kvar]	211	211	208
Billed Reactive Power	[kvar]	45	55	52

3.2.6 Reactive power compensation demonstration: Reactive power at night

The second demonstration tests the usage of the PV inverter to consume reactive power at night. The motivation for the demonstration arises from the increased reactive power production of the cabled

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distribution grid in Helsinki as well as decreased reactive power consumption and increased reactive power production of the loads connected to the distribution grid. The increased reactive power production is mainly caused by the capacitive nature of a cabled network and its low loading at night. The PV inverter could be beneficial here, as it is normally offline and its capacity is unutilized when the active power generation drops to zero after sunset. Since the inverter enables reactive power consumption and injection without PV generation, it can be exploited as a reactor when the grid needs compensation at night.

To demonstrate the reactive power consumption at night, one of the PV inverters is set to consume 100 kvar when it normally goes to idle after sunset. Active power generation levels less than approximately 5 kW result in the transition to reactive power consumption state. Conversely, the inverter starts to generate active power to the grid if the active power from the panels exceeds the level of 5 kW. In practice, low voltage level at the DC bus (PV panel side of the inverter) triggers the transition to consumption state. The inverter can provide compensation 90 % of its nominal rating but only a part of that capability is used for the demonstration purposes. The demonstration was performed during the timespan from 11.9.2017 to 29.9.2017.

From the demonstration period, the reactive power consumption of the PV inverter and its transformer is presented in Figure 10. As seen, the consumption is close to the set 100 kvar during nighttime. The measurement point is on the medium voltage side of the system’s transformer, which could explain the slightly higher consumption visible in the figure. The daytime consumption can also be explained by the reactive power demand of the transformer. This correlation between the active power generation of the solar power plant and its reactive power consumption is clearly visible in Figure 11, which shows these values for the first demonstration week.

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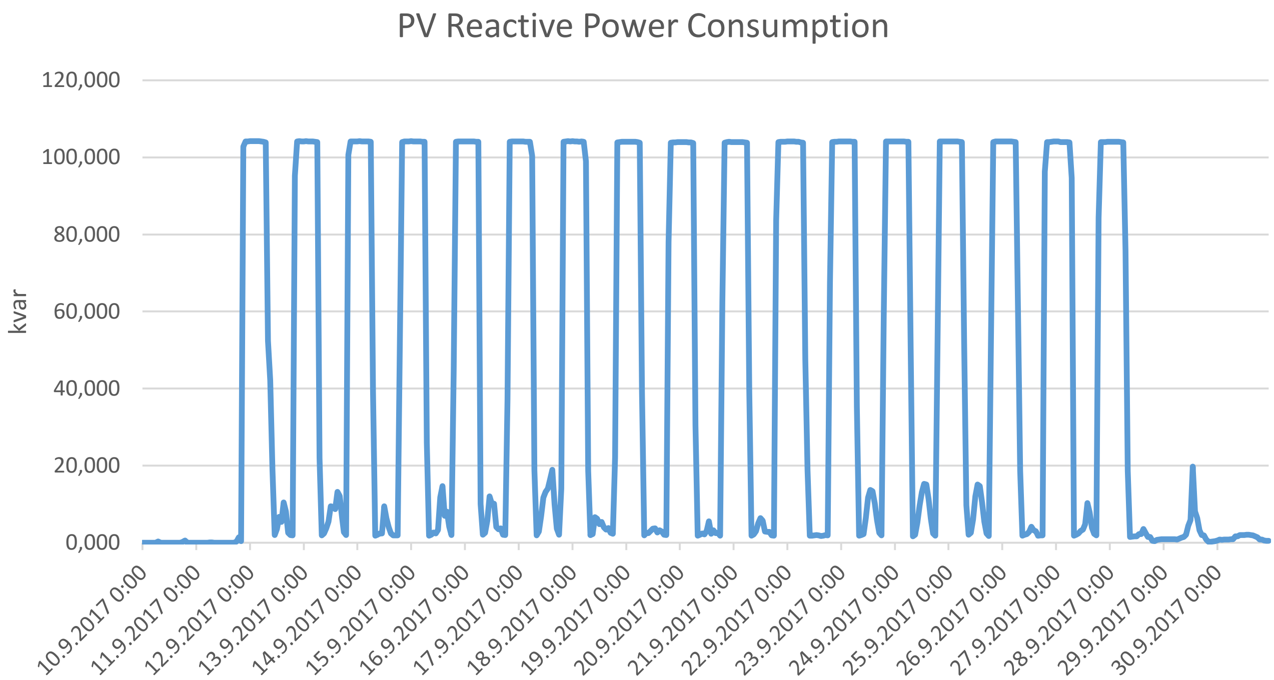

Figure 10: Reactive power consumption of the PV inverter and its transformer. The inverter has been utilized to provide compensation at night

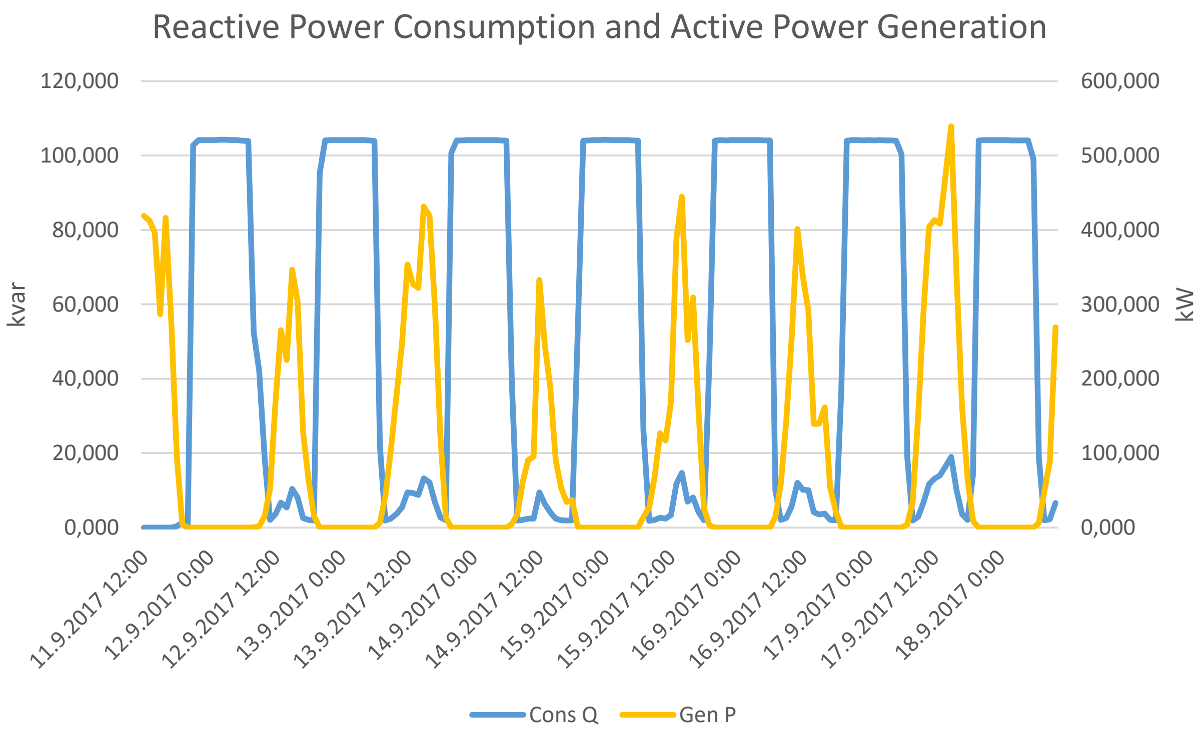

Figure 11: Reactive power consumption of the solar power plant (Cons Q) and its active power generation (Gen P) zoomed to the first week of the demonstration period

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Lastly, the reactive and active power consumption of the plant during the first week of the demonstration period is shown in Figure 12. One should note that the power flow direction from the measurements is from the grid towards the power plant. That is, during daytime, the active power consumption of the plant (e.g. losses in the inverters) are taken from the plant's active power generation, whereas they are drawn from the grid when the generation is low. As it can be seen in the figure, the active power consumption of the plant, approximately 4-5 kW, is drawn from the grid when the inverter provides reactive power consumption. According to the inverter manufacturer, the maximum efficiency of the inverter is above 98 % and its self-consumption 500 W. The measured losses are slightly higher, which could be explained by non-optimal operating point of the inverter and the active power losses of the transformer.

In order to make the reactive power compensation economical, the compensation should be sold to some party (e.g. DSO) so that the costs due to the losses could be covered. Furthermore, according to the inverter manufacturer, the maintenance interval of the inverter fans and auxiliary power sources approximately halves if the inverter provides compensation when active power is not generated. This naturally causes costs. At the moment of the demonstration, no monetary compensation was received from the provided reactive power consumption.

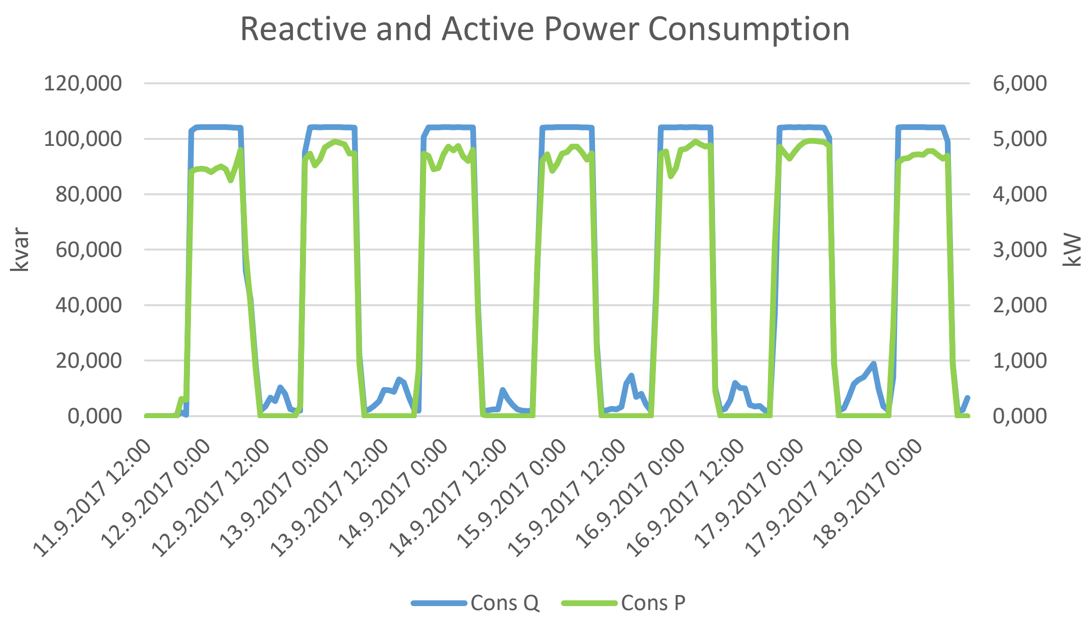

Figure 12: Reactive (Cons Q) and active power (Cons P) consumption of the solar power plant measured from the medium voltage side of the plant transformer

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3.3 Replication potential

Kivikko provides an attractive location for compensation demonstration because of its notable active and reactive power consumption. Some potential targets for compensation are ice halls, swimming halls, logistics centers, greenhouses, large cold rooms, shopping malls, office buildings, and farms. That is, buildings with a plenty of lighting, cooling, or ventilation load or other consumption with grid-connected motors (connected without an inverter). Low-loaded cable networks are also suitable targets as they produce reactive power, which may need compensation. However, the challenge is here that the conventional reactive power payments and their penalizing nature does not motivate the customers to increase their reactive power consumption when compensation is required. New products are required instead if the network users want to be further activated to provide compensation.

Another location for compensation demonstration was also initially considered during the project. This location, Suvilahti, was eventually discarded as a not attractive location for two reasons. Firstly, there already exists a battery storage at the site, which is able to provide compensation and voltage regulation continuously. Secondly, the inverter of the Suvilahti solar power plant is not oversized, that is, active power curtailment may be needed if a part of the capacity is reserved for reactive power compensation. The curtailment would reduce the profitability of the plant.

In general, solar power plants can be utilized effectively in locations where the active power generation of the plant covers a most of the local consumption and the plant's compensation ability can be used to improve the power factor of the consumption site. With the reactive power injection or consumption of the plant, reactive power payments are possible to reduce or avoid. Nevertheless, the compensation with a solar power plant is not free of charge, for example, due to reduced efficiency and possible modifications required by the plant. Thus, the incentive to utilize it in the compensation should be sufficient.

In the studied distribution network, the reactive power payment is based on the maximum monthly reactive power exchange with the grid. Therefore, the best benefit is achieved if the compensation is scheduled to occur at the moment of the maximum value. This would basically require smart and dynamic control, which may be complicated to implement. Alternatively, the inverter can be set to provide compensation with fixed settings (fixed reactive power value or power factor) continuously but this means a significant increase in the inverter operation time. The control strategy selected in this demonstration would provide the best outcome if the maximum compensation requirement occurred when the plant is generating but the generation is low. The business models with reactive power compensation are presented and discussed more in detail in deliverable D4.7 Report on monitoring and control concepts and improvements.

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4. Implementation of solar power plant

The purpose of this chapter is to, at first, describe the original plans to engage citizens in co-creation of new concept for solar power plant extension for Korkeasaari Zoo. The subchapter 4.1 describes the challenges faced with the planned co-creation of new PV business model. Eventually the plans to extend the PV production in Korkeasaari Zoo were cancelled and the mySMARTLife action number 17 was replaced with another solar power plant implementation, Messukeskus PV, that was being planned by Helen. The subchapter 4.2 discusses the business model and implementation of designated solar panels of Messukeskus solar power plant. Designated solar panels refer to a concept where customers can rent panels from the solar power plant.

4.1 The original plan to implement a solar power plant at Korkeasaari Zoo

Korkeasaari is one of the oldest Zoo's in the world and it has been founded in year 1889. In 2017, there lives over 130 different animal spices: birds, reptiles, mammals and amphibians. Korkeasaari island locates near Zone 2, one of the mySMARTLife project areas. Korkeasaari itself develops and improves its actions with top priority being in animal's welfare. Korkeasaari has an ongoing program called "Carbon neutral Korkeasaari" which aims at improving energy efficiency, reducing waste and emissions and with these actions ultimately in carbon neutrality. The carbon neutrality is sought to be met in 2030 (Korkeasaari 2019). The transportation within the zoo but also the arrival of the visitors, recycling, smart solutions to improve energy efficiency and renewable energy sources are the major players in the big picture when seeking the carbon neutrality. The map of Korkeasaari Zoo in 2017 is presented in figure 13.

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Figure 13: The map of Korkeasaari Zoo in summer 2017. Source: Website of Korkeasaari

Korkeasaari has an ecosystem very suitable for solar energy. The solar power potential of the island has been studied and available rooftop area that can be covered with solar panels can be found up to 100 kWp. Already 20 % of suitable rooftops has been installed with photovoltaic panels (PV panels) and within mySMARTLife the original plan was to install more. The solar energy reduces emissions and the carbon footprint and hence makes the island cleaner place to live and visit.

Korkeasaari is part of the City of Helsinki and it has been an own city organization but from 1.1.2018 the Korkeasaari Zoo has been run by a non-profit trust. Korkeasaari depends on funding and hence readiness to expand for example the existing solar power plant might not be straightforward. Different models to expand the solar power plant were taken into account during the planning work. Some of the solar potential needs to be funded by Korkeasaari but during the planning phase, Helen presented a few profitable models to build solar power plants in co-operation with Korkeasaari. For example, by using Helen's Power Purchase Agreement –model (later PPA), Korkeasaari would not need to invest in solar power plant itself. Instead, Helen would do the investment and take care of the power plant throughout the contract period. This way, Korkeasaari would be only paying the agreed €/MWh price of produced solar power. This was seen as a one possibility for Korkeasaari to increase renewable share and to meet the 100 kWp capacity reservation fast.

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Additionally, one aim in mySMARTLife is to activate and involve citizens to participate and take responsibility in climate change related actions. Within citizen engagement activities of mySMARTLife, a concept for new product or service for solar energy was aimed to be co-created. The target of the new product or service was to introduce an alternative way of funding a solar power plant. The concept work is described in chapters 3.1.1 and 3.1.2. although the plans to extend solar power production in Korkeasaari during mySMARTLife project were eventually cancelled and replaced with another concept in another location in Helsinki.

4.1.1 Co-creation of new concept for solar power plant extension

This chapter describes the co-creation concept that was targeted to be used in the extension of Korkeasaari Zoo PV plant. As it was already stated in the deliverable, the presented co-creation concept was not implemented since the plans for the PV plant extension during mySMARTLife project were eventually cancelled and the action was replaced with another implementation of PV plant.

Korkeasaari itself has been selling an entrance ticket in their online store to protect endangered felines and for example, one can support endangered Amur tigers and leopards by buying “Tiger sponsor” ticket in 50 € price. The sponsor ticket allows to visit the zoo once within one year of the purchase. The revenues are donated as unabridged to Amur Leopard and Tiger Alliance (ALTA) projects protecting wild Amur tigers and leopards. There is hence evidence of Korkeasaari trying to gather donations for good cause, however the tickets costing extra money to the visitor has not attracted larger crowds but only approximately 1 % annually sold tickets were these so called more expensive protection tickets.

The very first product concept in mySMARTLife project related to Action 17 Solar Power Plant implementation for Korkeasaari Zoo (50-200 kW) was to design a product that would cost little extra to the customer and the extra revenue would be saved and used as unabridged to invest in solar power plant. Two suggested products were coffee (solar coffee), which would cost 0.5 € extra, and another product was an entrance ticket (solar ticket) which would cost 20 % extra compared to the normal adult ticket. Based on the previous evidence from protection tickets, Helen and Korkeasaari together decided that the so called “solar ticket” would turn out to be also a margin product because its resemblance to the animal protection tickets.

To collect feedback and get the Korkeasaari visitors invested in the new concept Helen decided to change the approach and host a series of co-creation workshops. The plan was to host three workshops where

1) the participants could freely vision new ideas and while doing so they reveal their set of values and what motivates them in solar energy and animal welfare,
2) next three more concrete ideas would be formulated into attractive product or service concept by the workshop participants and
3) finally the ultimate concept would be tested and finalized.

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The framework planned for the first workshop is presented in annexes. In the best scenario, Helen would have been able to find the concept with the active citizens during the workshops and that concept would have been implemented in Korkeasaari during summer season 2018.

However, Helen foresaw some risks with the citizen engagement among the optimum scenario where we hit the jackpot. The pros and cons are evaluated in Table 4.

Table 4: The success factors and risks related to the co-creation workshops

SUCCES FACTORS	RISKS
Attractive concept	No one comes to the workshops
The visitors get more involved with Korkeasaari	The communication is challenging
The children learn about protecting animals and environment	People try to save the world but do not concentrate to vision the new solar concept

The framework of the workshop was supposed to be held in the 5th of October 2017. Several email lists, flyers in Korkeasaari as well as social media channels were used by Helen, Korkeasaari, City of Helsinki and Forum Virium to promote the workshop. After all, only three people signed up for the workshop and hence it was cancelled. The lesson learnt from the workshop planning was that even when many people showed their interest in the workshop through Facebook event, in reality people are not ready to sacrifice their own free time and commit to make the extra effort.

On the basis of this learning, Helen changed the approach again. Helen planned two different options, one that comes close to the original idea of designated panels and another one to enable citizens to do testing of new products and services via website. On the website we could

1) create questionnaires related to relevant themes,

2) ask citizens to comment on new products and services and

3) let citizens leave their ideas how to add more solar energy in Korkeasaari Zoo.

The other option was to integrate Helen's two products, PPA and designated panels. The PPA price would reportedly have been lower because designated panels bring supplement income. However, after discussions on the possibility of a combination of PPA model and designated panels, Korkeasaari decided not to expand the existing solar panels and the original plans to extend the solar production in Korkeasaari

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during mySMARTLife project were cancelled and the action was replaced with a different concept in a another location. The reasons that eventually led to the cancellation of original plans were:

1) Lack of interest from public to the initial financing model
2) Implementation of the actions in Korkeasaari became uncertain due to organizational change in the City of Helsinki (Korkeasaari was formerly part of the city organization but in the beginning of 2018 it became a foundation run entity)
3) Electricity system issues (several changes to electricity systems would have been required to increase PV production in the area).

4.1.2 Results, replication potential and replacement of the original plan

As a result, it was found out that citizen engagement is difficult and even though the community and the active visitors exist, it is hard to motivate people to spend their free time for someone else’s benefit. Another drawback in recruiting people to the first workshop was probably the lack of commitment since the decision to participate was not forced by a person, instead it was voluntary enrolment by email.

Regarding the results it should be noted that next time with citizen engagement events when the crowd will be ordinary people it is recommended to use a recruiting firm who makes sure that the volunteers signed up for the event actually show up. The replication of such workshop series is possible but the lessons learned from Helen’s experience should be noted, since the solar power plant extension at the Zoo was not in this case successful.

However, potential can be seen in the combined product of PPA (power purchase agreement) and designated panels and this model could be applied to ecosystems where the visitors have some emotional bond towards the place they are visiting. In zoos, in general, the animals are the motivating factor to rise interest as well as attract younger and older. Another location where such concept would be replicable is amusement parks, where on the other hand all the fun facts and themes could be applied to designate the panels.

Korkeasaari Zoo PV power plant extension was replaced with another PV plant concept in another location in Helsinki and therefore, mySMARTLife action 17 was changed to “Solar Power Plant implementation in Helsinki”. Helen had other plans to implement new PV production in Helsinki, which also engages citizens and therefore it was decided that the action 17 will be replaced with Helen’s other plan, implementation of a third designated solar power plant in Helsinki.

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4.2 Solar Power Plant Implementation in Helsinki (Messukeskus PV)

Helen's goal is carbon neutral energy production by 2035 and solar power is a part of the solutions to reach the targets. In 2018, Helen decided to invest in a third designated solar power plant after the success it had experienced with the first and the second designated solar power plants. The demand from customer's side has been high for a third designated solar power plant, since both of the existing designated panels, in Suvilahti and in Kivikko, were sold out. This chapter describes the success of the business model of designated solar panels and the implementation of the third designated PV plant to the rooftop of Messukeskus, Convention and Expo Center in Pasila, Helsinki.

4.2.1 The business model of designated solar power panels

A designated panel is an effortless way of becoming a solar energy producer: by renting a solar panel anyone can use renewable solar energy without having to install panels on own roof. The customers of Helen can rent a panel currently from three designated PV panels: Suvilahti, Kivikko and Messukeskus. Table 5 depicts information about the PV plants.

Table 5: Information about designated solar power plants in Helsinki

PV PLANT	ANNUAL PRODUCTION	RATED POWER	SINGLE PANEL OUTPUT	NUMBER OF PANELS	INSTALLATION YEAR	EXPANDED
Suvilahti PV	274 MWh (2018)	340 kWp (PV plant in the roof)	285 W	1194	2014	In 2018 with 23.52 kWp to the wall
Kivikko PV	783 MWh (2018)	850 kWp	285 W	2992	2016	-
Messukeskus PV	445 MWh (estimated, 1st phase)	500 kWp (1st phase)	315 W	1589 (1st phase)	2019	2nd phase ca 300 panels (100 kWp)

Helen built the first solar power plant with the concept of designated solar panels in Suvilahti in 2014 and it was the first solar power plant that offered designated solar panels in Finland. The business model was successful and there was demand to build second solar power plant with the same opportunity for customers to rent PV panels. In 2016, Helen installed the second designated PV power plant to the rooftop of Kivikko Arctic sports centre.

In 2018, Helen decided to invest in a third designated solar power plant after the success it had experienced with the first and the second solar power plants. Designated panel is a good alternative for persons living e.g. in apartment blocks, who do not wish or have the possibility to invest into own solar panels but are still interested to participate and support renewable energy. The rented panel increases the volume of solar power in the Nordic electricity market, and the whole output of the rented panel is deducted from customer's electricity bill.

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The driver for a customer to rent a panel is the easy way to contribute towards increasing renewable energy in Finland. When the customer buys a designated panel, the volume of solar energy produced in Finland increases by precisely the output of the panel. The designated panels are intended for customers who have an electricity contract with Helen Ltd. If a customer does not have an electricity contract with Helen, this is set up separately. The designated panels are currently sold for a monthly charge of 4.40 €. Helen will credit the electricity produced by the panel in accordance with the spot price. The production of the solar power plant varies with the seasons, but an average credit for a panel is about one euro per month, leaving approx. EUR 3.40/mth to pay on the panel (Helen 2019b). The panel's production is deducted from customer's electricity bill. Economic savings do not drive the purchase. The driver is the easy access to take part in solar energy production and support renewable energy sources.

For a monthly price, a customer receives the output of a single panel. The value of the panel's electricity output is deducted from the customer's monthly charge in accordance with the price of Helen's Exchange Electricity product in force. The nominal output of a single panel is 285 W at the Suvilahti and Kivikko power plants and 315 W at the Messukeskus Expo and Convention Centre power plant. The output of a panel naturally varies with weather conditions and the time of the year as illustrated in figure 14. The estimated annual output of a single panel at the Suvilahti and Kivikko plants is about 230 kWh and at the Messukeskus plant about 280 kWh. The output is certified with guarantees of origin.

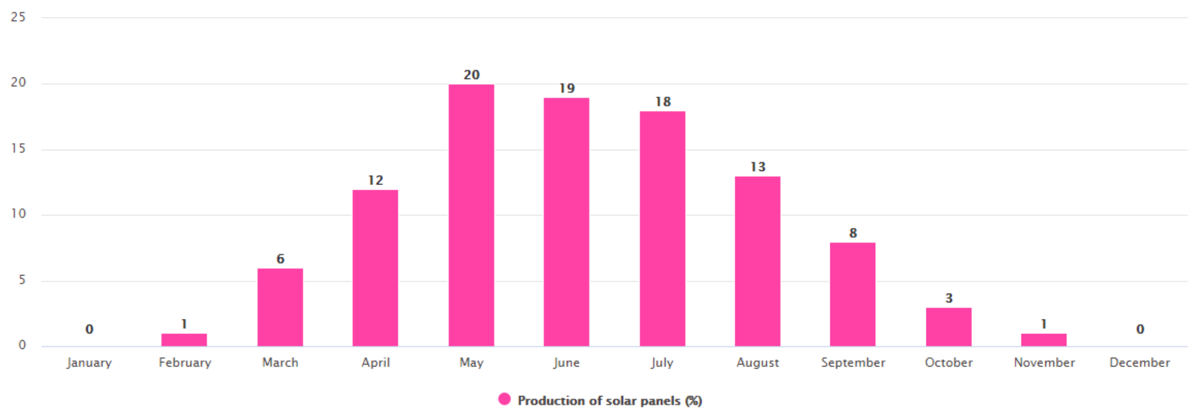

Figure 14: Estimated production of solar panels in Finland (%). The production of the panel is highest during summer months. (Helen 2019c)

4.2.2 Drivers and motivations of the innovation

Helen's designated panels give an easy way to the customers to participate in solar energy production. The product is addressed to environmentally conscious persons, who are interested to participate in solar energy production and reduction of CO_2 emissions. In addition, companies have rent PV panels from the PV plants and therefore companies willing to support PV production are also a target customer group. Furthermore, customers without possibility to invest in own solar power plant still have an opportunity to

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support solar energy production in Finland. From the perspective of the customer, designated solar panels are an easy way to support environmental friendliness and renewable energy production. Economic savings do not drive the purchase, the motivator is the climate awareness and an easy way to support renewable energy production.

In Helsinki, the demand from Helen's customers side has been high for designated solar panels, since Messukeskus PV was already a third solar power plant with the designated panels concept. During early spring 2019, both of the designated solar panels of Helen (Kivikko PV and Suvilahti PV) were sold out. Therefore, there was demand for a third PV plant offering the same possibility to rent PV panels. As of October 2019, already over 1200 panels were reserved from the rooftop of Messukeskus. The number of reservations underlines the great success of designated solar power plants in Helsinki. Therefore, the product has answered to the needs and expectations of the target customer group. The drivers of the solution include also growing solar energy market and increased interest to participate in PV production.

The main motivations for Helen to implement three designated solar power plants in Helsinki have been to answer the needs of our customers, to increase the share of solar energy production in Finland and to reduce the CO_2 emissions of electricity production. From the perspective of the property owner (offering the rooftop for the installations), the main motivations have been responsibility, sustainability, reduction of CO_2 emissions and the possibility to participate in a solar energy project. In addition, the new solar power plant in the rooftop brings media interest to the property owner.

4.2.3 Marketing of designated solar power plants

Helen has used different social media channels as well as billboards (e.g. located near metro stations) to market designated panels. In addition, newsletters were published and cooperation has been done with social media persons. Furthermore, designated panels have been promoted in different events that Helen has participated. Moreover, a media event at the installation site has also been organized when the new power plant is close to opening.

Customer can rent a PV through Helen's webpage or through customer service. The customer can select the panel(s) from online reservation system (Figure 15). In addition, customers can download a csv file from the webpage of Helen containing the hourly series of the production of the PV plant as well as use live monitoring to see the power at the moment and produced energy during the day (Figure 15).

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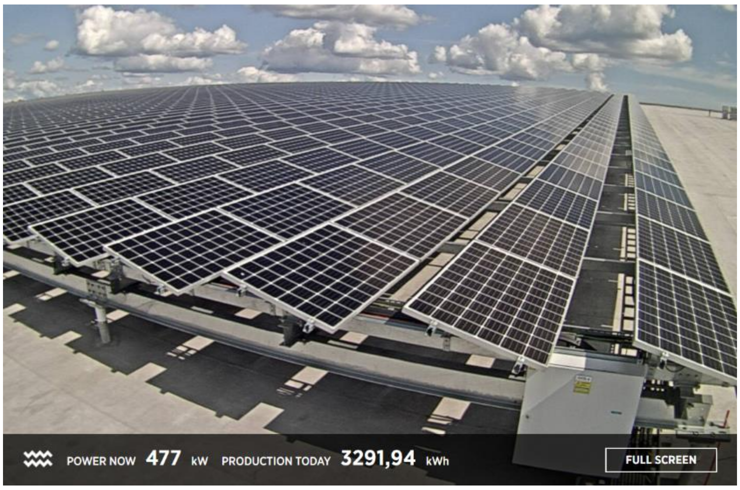

Figure 15: Live monitoring of the Kivikko PV plant via Helen's webpage on 18.7.2019 at 15:05

4.2.4 The implementation and funding of Messukeskus solar power plant

One of the largest solar power plants of Helsinki is built on the roof of Messukeskus, Expo and Convention Centre located in Pasila, Helsinki. 1,589 solar panels are installed on the roof during the first phase and 300 panels more in the second phase. After the installation of both phases, the power output of the PV plant is 600 kWp.. The production of the plant equals the annual consumption of more than two hundred one-bedroom apartments. When the Messukeskus solar plant is completed, it will increase the solar electricity capacity connected to the Helsinki distribution network by 11 %.

In order to be successful, the designated solar panels always need an investor and seller of the product (Helen), energy companion (owner of the property) and customers. All three are needed to implement the solar power plant and to produce local, renewable and emission free energy. In addition to these three categories, several other parties are needed including e.g. manufacturers of the components of the PV plant, deliverer of the components, contractors, permissions from City of Helsinki to build a PV in the location and partners of technical planning of the PV plant.

The funding of the investment costs of Messukeskus PV consists of Helen's own investment and energy aid of Business Finland. The energy aid of Business for solar electricity projects in Finland was 25 % until 30.4.2019 and 20 % from 1.5.2019. (Business Finland 2019). After the implementation, Helen will receive revenues from selling the electricity produced by designated solar panels to the customers.

The implementation of Messukeskus will be finalized in the end of 2019. Customers can already rent a panel via online reservation system or via customer service (Figure 16). A media event to promote the Messukeskus panels was also organized in fall 2019.

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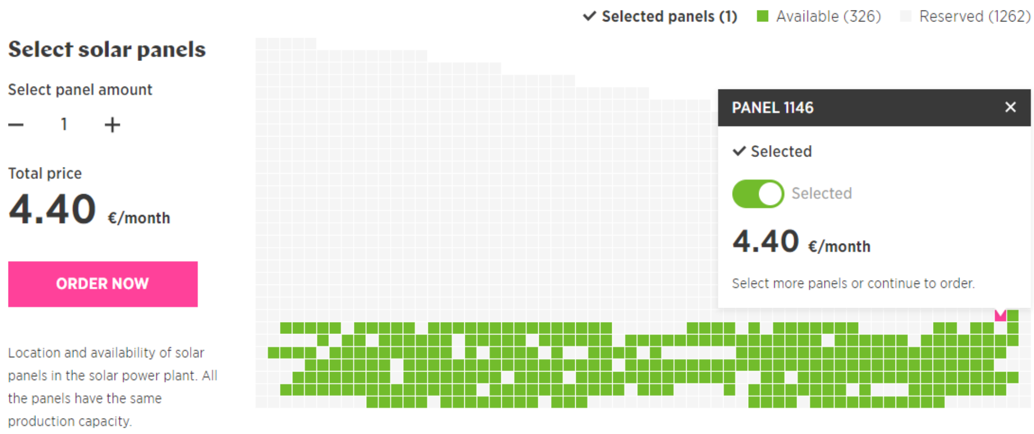

Figure 16: The reservation situation of Messukeskus as of 5.11.2019 shows great success with the business model of designated panels in Helsinki. Already 1262 panels were reserved. (Helen 2019c)

4.2.5 Replication potential and future evolution

Based on Helen's experiences, the replication potential of designated solar panels has been great in Helsinki since Messukeskus PV was already a third designated solar power plant of Helen. In spring 2019, the panels of Kivikko PV and Suvilahti PV were both sold out and the same success has continued with Messukeskus PV. In the end of October 2019, already 1200 panels (ca 75 %) were reserved from the rooftop of Messukeskus.

In Helsinki, the business model of designated solar panels has been successful. However, the business model reaches the certain type of customers (environmentally conscious customers that are also willing to use some money to rent a PV panel and support solar energy production). The solution does not reach customers that are also willing to have the economic benefit and for whom the environmental friendliness alone is not a good enough reason to rent a PV panel.

The business model of designated solar power plants is replicable especially in cities with growing interest in solar energy production and environmental friendliness. The business model has been a success in Helsinki, but this does not necessarily guarantee that the same kind of success could be reached in other regions or in other countries. The success of the business model is based on the knowledge of customers and on the knowledge that a customer segment willing to rent a PV panel and participate in renewable energy production without economical incentive exists. Therefore, the successful implementation of the business model needs local knowledge on the customer segments and their needs as well as successful marketing of the new product.

The possible future evolution of the model could be to sell shares of the solar power plant to companies. This could be an alternative possibility for companies to participate in solar energy production if the company is not willing to invest in own solar power plant or in the case that it is not technically possible to install PV panels to the rooftop of the company's building. There is also an economical aspect in buying a

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share of a PV plant, since, on the contrary to renting a designated panel, it will pay back. In practice, this would mean crowdfunding of solar power plant (an energy company and other interested companies invest in a share of the PV plant).

The evolution of the service also includes packing of different types of RES and energy efficiency services and solutions to answer the specific needs of the customer. An example of energy partnership is the partnership between Helen and Olympic Stadium in Helsinki. The Olympic Stadium is currently under modernization with an aim to improve energy efficiency with several types of actions. A part of the planned collaboration is to implement a solar power plant on the Olympic Stadium roof, with designated panels available to rent from Helen (Helen 2019d).

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5. Conclusions

This deliverable discussed the technical and business concepts of solar power plants. The chapter 3 of this deliverable described the technical demonstration of reactive power compensation with Kivikko solar power plant in Helsinki. The subchapter 4.1 discussed the planned concept to implement more solar energy in Korkeasaari Zoo, which was eventually cancelled and replaced. The original plans of the mySMARTLife action were replaced with another PV concept in another location Helsinki. The subchapter 4.2 presented the successful implementation of the new plan. A new solar power plant was installed to the rooftop of Messukeskus, Convention and Expo Centre in Pasila, Helsinki. The output of the new solar power plant will be 600 kWp and it is finalized by the end of 2019. The approach in this deliverable is well in line with the task 4.3 Smart Energy Supply and Demand objectives but also resonates well with the project level goals of increased use of renewable energy and reduction of CO_2 emissions.

As described in chapter 3, test periods of reactive power compensation with the Kivikko PV were done during summer and autumn 2017. At first, the inverter of the solar power plant was set to compensate the reactive power produced by the Arctic Centre and hence slightly reduced its monthly reactive power payments for local distribution system operator, Helen Electricity Network Ltd. The tests showed that the inverter is capable of compensating the reactive power during active power production. The slight decrease in measurements of reactive power was observed based on the collected data and hence the concept works technically. The second test was done during nighttime without solar power production. The objective of the nighttime test was to provide reactive power compensation (consumption in this case) to the local distribution system operator, Helen Electricity Network Ltd. The test was technically successful. However, no business potential exists for such an operation since no local DSO reactive power market currently exists. Furthermore, it can be also argued whether compensating reactive power with solar plant's inverters is economically viable, since the compensation will affect the lifetime of inverters.

The chapter 4 of the deliverable focused on business models and implementation of solar power plants. The concept development in Korkeasaari was originally targeted to meet the mySMARTLife project goals in terms of citizen engagement, but eventually the original plan was cancelled and replaced with another PV plant business concept in another location in Helsinki. It was observed that engaging citizens is far from easy and the inquired input from volunteers must be made as easy as possible to succeed. The original plans of the mySMARTLife action to implement solar power plant in Korkeasaari Zoo were cancelled mainly for three reasons. Firstly, there was a lack of interest from public to the initial financing model. Secondly, organizational change in the City of Helsinki (Korkeasaari was formerly part of the city organization but in the beginning of 2018 it became a foundation run entity) affected the plans. Thirdly, the

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electricity system would have required several changes in order to implement more PV production. However, the lessons learned and the best practices found can be replicated in similar occasions.

The plans of Korkeasaari PV were replaced with Helen's other planned investment in solar energy, designated panels to the roof of Messukeskus, Convention and Expo Centre in Pasila, Helsinki. The concept of designated solar power plants contributes to the mySMARTLife project goals in terms of citizen engagement and increased use of renewable energy. The concept of designated solar panels, i.e. customers can rent a panel from the PV plant, has been very successful in Helsinki. The third designated solar power plant, Messukeskus PV, will start operations in the end of 2019. The designated solar panels have received great interest from the public since, as of October 2019, already over 75 % of the panels of Messukeskus PV were reserved by the customers of Helen.

The business model of designated solar panels is targeted for environmentally conscious persons willing to also invest some money to participate in local solar energy production. The business model of designated solar power plants is replicable especially in cities with growing interest in solar energy production and environmental friendliness. The business model has been a success in Helsinki, but this does not necessarily guarantee that the same kind of success could be reached in other regions or in other countries. Therefore, the successful implementation of the business model of designated panels needs local knowledge on the customer segments and their needs as well as successful marketing.

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Annex: The co-creation workshop 1 framework and the participants

Held on 5th October 2017 at 16.30-19.00, Kalasatama Living Lab, Sörnäisten rantatie 22, 00540 Helsinki

Start (10 minutes)

- Welcome, motivation and the goal of the workshop

Stimulation (20 minutes)

- Couple task: What does the sun and animals have in common? How does these two things relate to each other or to one's everyday life?

Processing (60 minutes)

- Introducing the progress of the workshop from now on
- Divide the group into four (or two depending on the number of participants) smaller groups.
  1. First set of questions: How do you make decisions between different options when purchasing consumer products and what drives you to make these decisions? What motivates you to choose certain electricity contract, for example why would you buy environmental electricity?
  2. Second set of questions: What makes you feel good in Korkeasaari? Where/what is your favorite spot in Korkeasaari? How and where animals in Korkeasaari use solar energy? How can different energy solutions improve the animals' well-being?
- Two set of questions around which the participants work: 30 minutes work with the first round, then 10 minutes break and switch between the question groups. 20 minutes time to familiarize with the other groups ideas and summarize the results.

Conclusion (15 minutes)

- One of the group members presents the outcome: ideas or themes around the sun, solar energy and the zoo environment.
- Voting amongst the whole group the best ideas for further assessment in the coming workshop 2.

Finish and thanks (5 minutes)

- Summarize the results and inform the rough content of the next workshop 2.

List of participants

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- Facilitators
    1. Krista Jaatinen (HEN)
    2. Kristiina Siilin (HEN)
    3. Antti Rautavuori (HEN)
    4. Timo Ruohomäki (FVH)
- Workshop participants: none

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