Ref. Ares(2019)7731672 - 16/12/2019

Demonstration report including KPI-Evaluation for all use cases
Version 1.0

Deliverable D5.10

16/12/2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n°731289

ID & Title :	D5.10 – Demonstration report including KPI-Evaluation for all use cases		
Version :	V1.0	**Number of pages :**	76

Short Description

Deliverable 5.10 presents results and lessons learned from the field tests carried out in the German demonstrator and evaluates the key conclusions drawn from the three use cases “Feed In Management”, “Ancillary Services” and “Demand Response”.

Revision history

Version	Date	Modifications’ nature	Author
0.0	05.11.2019	Document initialized	Gross
0.1	10.11.2019	Write Up	Gross
0.2	15.11.2019	Peer Review	Bruschi
1.0	16.12.2019	Final Version	Gross

Accessibility

☒Public	☐ Consortium + EC	☐ Restricted to a specific group + EC	☐ Confidential + EC

Owner/Main responsible

Name(s)	Function	Company	Visa
Gross	WPL	Avacon	

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Work Package ID	WP 5	**Task ID**	T5.9

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EXECUTIVE SUMMARY

Deliverable 5.10 presents the results and conclusions derived from the field tests in work package 5 in the German demonstrator. The report revisits the main stages of the work package, reviewing the system design and implementation of the Smart Grid Hub, customer acquisition and management and the experience and key learnings from 3 use cases. During the field test phase, the use cases “Feed In Management”, “Ancillary Services” and “Demand Response” were targeted. Use cases were carried out using a newly developed control platform and flexibility provided by private household customers, which were activated utilizing the smart meter framework as a data and command channel.

All use cases successfully demonstrated that a direct coupling of DSO grid operations with a smart meter framework is possible. This architecture proved to be highly secure and offered supreme scalability within a member state.

Use case 1 “Feed In Management” could show how the integration of small scale DER connected to LV networks can contribute to regional curtailments. The inclusion of LV connected devices offered flexibility in smaller increments, which in turn contributed to lower overall curtailments due to the higher precision and finer granularity of available flexibility.

Use case 2 “Ancillary Services” demonstrated successfully the basic principle of how a DSO could aggregate bi-directional flexibility from uni-directional sources such as rooftop PV or heatpumps. The idea was to combine readily available devices to a virtual source of flexibility at the DSO’s disposal. The results concerning technical and regulatory feasibility were positive, meaning that it could be done with the Smart Grid Hub and existing regulatory rules. In practice however, the share of bi-directional flexibility that could be harvested from uni-directional sources was comparably small. The causes were primarily meteorological but had also a regulatory element. Concerning the weather dependency, it came as no surprise that PV production generally correlates negatively with the demand in residential heating. From a regulatory perspective however, a few barriers surfaced. For one, the lack of a clear set of rules regarding the activation of EV chargers prevents the DSO from taking advantage of this flexibility. Batteries are limited in their ability to participate, because the current framework encourages behind-the-meter applications and doesn’t do a particularly good job of bringing behind-the-meter flexibility to the DSO. And finally, the way the activation concept for storage heating is designed, these devices are meant to charge during night times, when PV production is zero. Opening the storage heating business to the full 24h window at the DSO’s disposal could immediately raise the potential.

Use case 3 “Demand Response” demonstrated the effectiveness of flexible loads even under a simple demand response mechanism. The dynamic optimization of daily charging cycles for storage heaters could improve DSO economics and potentially even lower DER curtailments. Limiting heat pumps for short periods of time during peak demand could reduce stress on the network and improve the hosting capacity for growing segments such as EV.

Cost benefit analysis for work package 5 was overwhelmingly positive. The potential reduction in DER curtailments could save millions of Euros in lost generation. Advanced dynamic control mechanisms for flexible loads could likewise save on balancing costs and increase the hosting capacity for new customers.

From a regulatory perspective, work package 5 found that today’s rules on curtailments and flexible loads already enable use cases that can contribute to a more stable and cost effective operation of distribution networks. However, a number of barriers for flex-activation have been identified as well. Chief among which is the pending legislation on flexible load activation and the lack of incentives for residential batteries to provide flexibility in-front-of-the-meter.

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1. INTRODUCTION

1.1. Scope of the document

Deliverable 5.10 recollects results from the entire project in work package 5 and gives an overview over the key learnings and conclusions derived from the field test demonstrations in Germany.

1.2. Notations, abbreviations and acronyms

The table below provides an overview of the notations, abbreviations and acronyms used in the document.

Table 1 - List of Acronyms

ADMS	Advanced Distribution Management System
CLS	Controllable Load System
DER	Distributed Energy Resources
DSO	Distribution System Operator
EC	European Commission
HV	High Voltage
ICCP	Inter Control Center Protocol
KPI	Key Performance Indicator
LTE	Long Term Evolution (4G mobile network standard)
LV	Low Voltage
MV	Medium Voltage
OT	Operational Technology
PLC	Powerline Communication
SCADA	System Control and Data Acquisition
SGH	Smart Grid Hub
SMFW	Smart Meter Framework
SMGW	Smart Meter Gateway
UC	Use Case
UI	User Interface
UTC	Coordinated Universal Time
VHV	Very High Voltage

2. MOTIVATION AND GOALS IN THE GERMAN DEMONSTRATOR

Being at the forefront of the German energy transition, Avacon has been challenged by a fast growth of decentral generation. Particularly in the rural regions, Avacon is managing low- and medium voltage networks that are exporting a significant surplus of locally produced energy.

This influx of decentral generation has been a challenge for the existing networks, to an extent where investments in additional network capacity could not always keep up with the growth of decentral generation. A well-known fact is that today large amounts of renewable energy have to be curtailed in times of high stress on the grid to maintain safe and secure network operation.

Flexibility could help DSOs to reduce curtailments, by implementing strategies that allow for more precise control of generation and a local granularity of control signals. But how could DSO implement these new strategies?

InterFlex has developed a control platform that is bound to the national smart meter framework and allows DSOs in Germany to directly monitor and control flexibilities in households. This allows DSOs to identify critical situations earlier and better. With this, DSOs can carry out inevitable curtailments on a smaller regional scale and with a higher granularity and precision.

In addition, this new technology, dubbed the “Smart Grid Hub”, also enables a new approach for DSO-control of flexible loads. During the cold season electrical heating accounts for a large share of network load. This load can partially be leveraged as a source of flexibility, effectively coupling heating and power. The Smart Grid Hub enables DSOs to carry out existing double-tariff switching via the smart meter infrastructure. And accordingly advanced strategies for the management of flexibility become viable. For example, the double-tariff scheme in place today operates at fixed hours, activating all heating customers at once. The Smart Grid Hub allows DSO to switch each customer individually and to implement dynamic switching. This leads to a better distribution of the load during peak hours and enables additional use cases that could potentially lead to a reduction in grid balancing costs.

The Smart Grid Hub is designed to be a part of DSO grid control with a direct Inter Control Center Protocol (ICCP)-interface to the DSO SCADA and ADMS. It also integrates seamlessly with the national smart meter framework in Germany and creates a direct connection between DSO and LV-connected customers. As such, it removes the cost for connecting new flexibilities to the DSO-owned control infrastructure, instead it builds upon the smart metering infrastructure that will be deployed regardless.

Work package 5 and the German demonstrator have successfully developed and tested the control platform and all interfaces required to deploy a fully integrated solution. It has demonstrated successful use cases for smart curtailment of DER and DSO-owned demand response schemes. Other use cases could not be implemented as envisioned, for these the work package has highlighted the reasons why it could not be done and collected a number of recommendations for the regulator to enable even more use cases for LV-connected flexibility.

3. SOLUTION DESIGN

DSOs in Germany have a technical obligation to curtail and control small-scale generators to avoid violations of technical limits of the electrical infrastructure. The mechanisms are tightly regulated but have proven very effective and useful to keep the energy system safe and within its technical limits while allowing a fast connection of new DER to the network – even when a required grid expansion has not been finished yet. There is also a demand response mechanism in place that allows DSOs to control certain types of flexibility in exchange for a reduction in grid charge. Likewise, the load management mechanism has the potential to improve DSO operations and economics if it was applied in a smart and dynamic way. Three major technical limitations prevent DSOs today from taking full advantage of these mechanisms:

1. They lack the communication infrastructure to control a large number of small (LV-connected) sources of flexibility such as rooftop PV, residential energy storage or electrical heating appliances in a secure and reliable way.
2. They lack the data processing capabilities to handle and leverage a large amount of data from numerous sensors across the grid. The expected deployment of smart meters in Germany would create a situation where DSO had general access to large amounts of data but no tools to make sense of it.
3. They lack the computing power to derive a plan of action for flexibility requests originating in grid control.

The Smart Grid Hub was envisioned as an extension of today´s DMS/ADMS of a DSO and was supposed to address all the challenges mentioned above. A fully operational Smart Grid Hub would enable the DSO to:

1. Collect, process and store a vast amount of data acquired by a digital metering infrastructure on the residential level.
2. Derive switching and dispatch schedules for all connected sources of flexibility regardless of technology to ensure a safe, efficient and reliable operation of local MV and LV grids.
3. Carry out these schedules and switching programs via an individual and secure communication infrastructure to ensure a maximum of security and reliability in the process.
4. Be fully integrated with the national smart meter framework to keep costs for installation and onboarding of participating flexibilities as low as possible.

The Smart Grid Hub (SGH) is the central part of an integrated concept to enable the DMS of a DSO to access and directly control small-scale flexibilities of any type in response to violations of technical grid constraints or market signals. Other crucial parts of this concept were the communication infrastructure and smart-meter gateway administration, intelligent metering devices and control boxes on customer's premises.

The general protocol for the use cases during the Smart Grid Hub field test phase were as follows:

1. Grid control monitors the network and estimates of the state of MV- and LV-grids, based on technical data from grid sensors (voltage, current), customer sensors (consumption, feed-in) and external factors like the weather.
2. Based on these state estimates grid control can identify potential imbalances in specific areas of the grid or impeding or existing violations of technical limits like local voltage excess or current overload of assets (grid congestion). To bring the local grid back to a balanced state and / or to relieve local grid congestion a cascade of actions can be set off.
3. In the cascade of action grid control tries to re-balance the grid by altering the current state of operation with switching actions. The second step is to leverage local flexibility in order to relieve congestion and to return to a balanced state. If both these strategies fail, a more heavy-handed approach of grid safety measures has to be taken.

4. The SGH monitors the current status and availability of all sources of flexibility at all times.
5. If necessary, grid control can request a certain amount of flexibility in a specific area of the grid from the SGH. The SGH will determine the optimal strategy to satisfy these requests while keeping total intervention at a minimum.

At its core, the SGH consists of two parts:

- **A process unit** which is handling the requests and performs switching and controlling action with a reliability, security and availability to the standard of the grid control center itself. To ensure full compliance with the required standards the process unit must be located within the process IT environment.
- **A data unit** which consolidates and provides data from other sources within the company. The data unit synchronizes with other data bases on a regular schedule and provides data to the process unit at request. Crucially the data unit does not have to perform to the same standards as the process unit and could be located in the standard commercial IT environment.

3.1. Interfaces and integration with existing systems

The Smart Grid Hub acts as a central processing and data unit to leverage large amounts of data for grid optimization and automation. Figure 1 shows how the SGH fits into the general architecture.

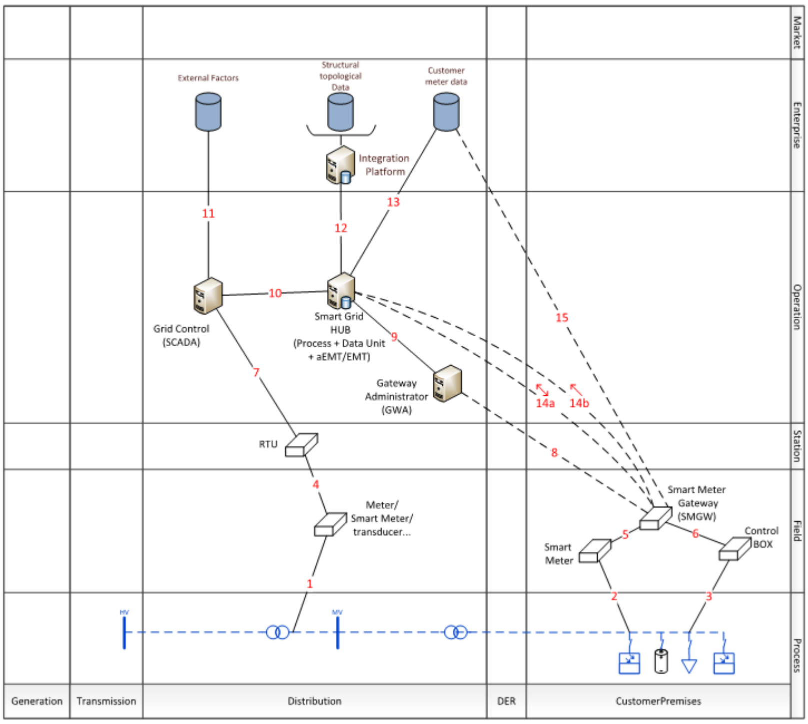

Figure 1: Smart Grid Architecture Model of the German Demo

3.1.1. Smart Meter Gateway, Control Box, Digital Meter

Customers were connected to the system via the smart meter framework in Germany. The Deployment of smart meters in the German market has been discussed for a while now. The official kick off is still pending. One of the preconditions for the rollout to commence is the availability of at least 3 certified smart meter gateway in accordance with the specifications defined by the federal agency of cyber security. At the time of writing this report, two have been certified and a third is announced for the end of the year.

The set up for connecting customers to the system consisted of an intelligent metering system (iMS) in accordance with the specifications of the smart meter framework in Germany. An iMS contains a digital meter, the smart meter gateway to handle communication, security and basic data processing capabilities. To enable active control of flexibilities by the DSO it further included a control box which replaced existing signal receivers previously activated via ripple control or radio signal.

Smart meter gateways are bound to a gateway administration service (GWA) that handles all access to iMS in Germany. To enable the InterFlex use cases an additional interface had to be added to the GWA and a few additional functionalities had to be developed for the SMGW.

3.1.2. Grid Control Center

The SGH was designed to be located within the grid control environment of a DSO. The current SCADA/ADMS system monitors the situation of the grid, determines switching schedules collects and stores data and provides state-estimates for the entire network operated by Avacon. The SGH was connected directly to the SCADA and received request and control signals from there. The fact that the SGH process unit was supposed to be located physically in the grid control environment proved to be an unexpected and significant challenge. Considered a part of the national critical infrastructure grid control is subject to a wide-ranging cyber security concept. The national agency for cyber security in Germany (BSI) classifies the threat potential for critical infrastructure as high. According to the 2019 annual report on cyber threats operational technology such as SCADA is less at risk than IT, but still the threat and potential damage remain high and give no reason to take this issue lightly.

The major challenge for InterFlex was to implement the interface between the SGH, which is located in the secure grid control environment, and the smart meter infrastructure, which is partially located in the internet. Technically the GWA is also hosted in a secure and certified environment and does not present much of a threat. The communication between grid control and GWA however is handled via web services. Additionally, the SIM cards in the smart meter gateways are located in the internet as well.

To make it work the IT architecture and communication had to be designed and reviewed carefully by cyber security experts and required the routing through several firewalls. To realize the final connection between the SGH and SCADA/ADMS further required the installation of a reverse-proxy solution. After all, the SGH could not be allowed to jeopardize grid controls cyber security certification.

4. CUSTOMER INVOLVEMENT

The focus of the German demo in Interflex was to establish a secure, reliable and efficient end-2-end communication between the DSO SCADA/ADMS and electrical devices on behind the meter that could enable the implementation of advanced strategies for grid operation. For the first time in Germany and Europe Interflex could demonstrate how even the smallest flexibility can be leveraged to effectively support the network and improve the integration of renewable energy without sacrificing economic principles or customer comfort.

In order to test the control solution and hypotheses concerning the availability and effectiveness of residential flexibility Avacon committed to the ambitious goal of 200 private customers to be involved in the real-life demonstrator.

The participating customers were to be equipped with

- A digital electricity meter to monitor the point of connection and provide data on power consumption, generation and local grid KPI.
- A smart meter gateway in accordance with federal technical guideline TR-03109-1 to handle all communication between household and external agents for maximum security.
- A control box to relay the control signal from grid control SCADA and the Smart Grid Hub to the flexible device.

To recruit enough pilot customers Avacon designed a multi-step acquisition process that involved the selection of a suitable region, the identification of potential candidates, a recruitment phase, an incentive scheme for participants, a technical evaluation and finally an ongoing customer care process. To ensure successful customer recruitment Avacon settled on a multi-stage approach as detailed below in Figure 2.

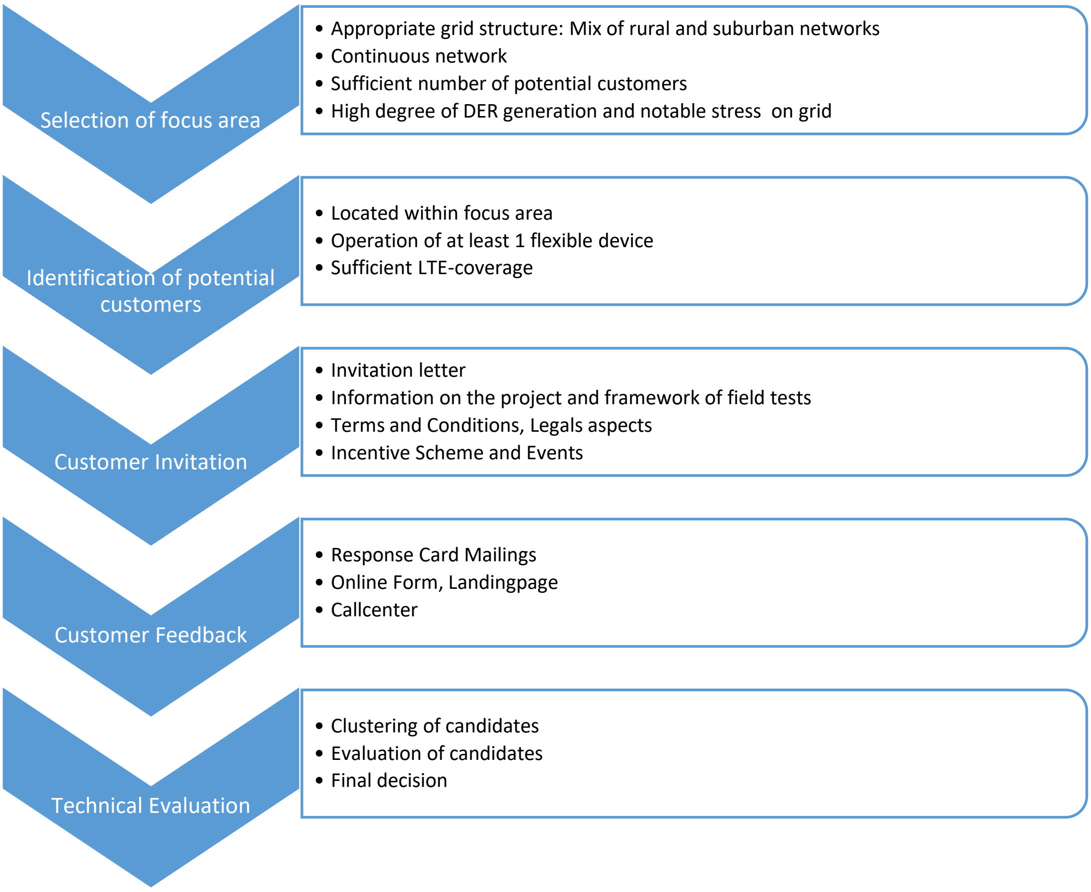

Figure 2 - WP5 Multi-Step Customer Acquisition Process

Based on the criterion “Continuous service area”, “number of potential participants”, a versatile grid topology and generation structure of renewables, Avacon made the decision to carry out field testing in the area in and around the city of Lüneburg. The focus area includes the city of Lüneburg and its surrounding communities as shown in Figure 3.

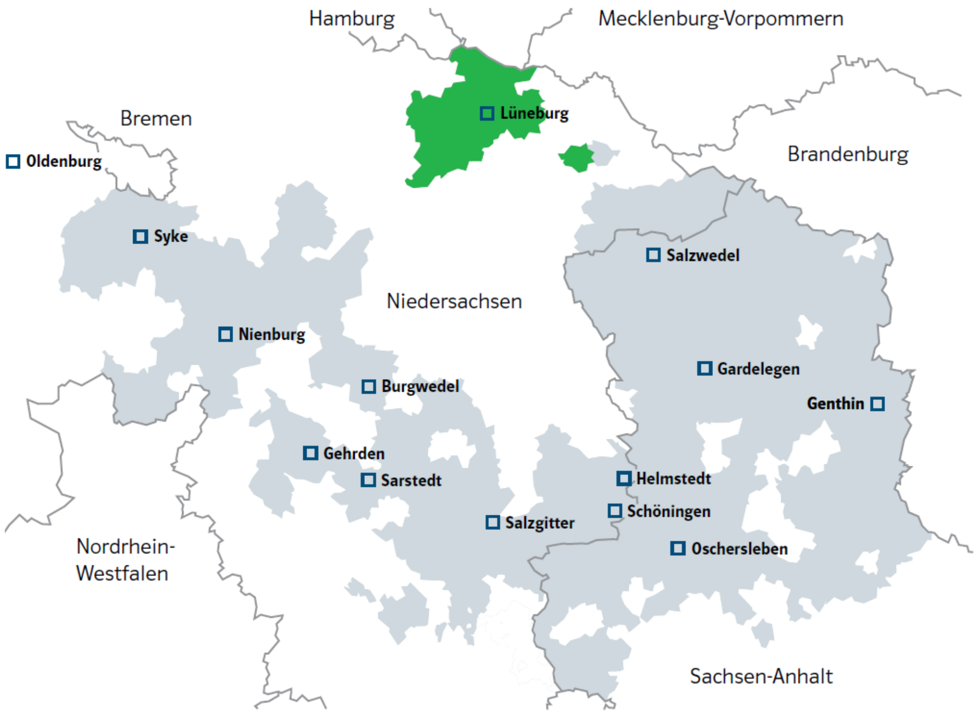

Figure 3 - Service Area of Avacon in and around Lüneburg

Located in the north of Germany, Lüneburg has shown significant growth of renewable energy in the past and reached a green power quota of 65 % in 2018. The generation structure in the area is characterized by many photovoltaic systems and a small number of wind turbines. The high number of small-scale flexibilities met the necessary requirement for the field test.

Table 2 – Total number and type of flexible devices in focus area

Type	Number of devices
Generator	1,636
Electrical heater, heat pump	3,613
Battery storage	9

4.1. Customer Invitation

The strategy to engage a sufficiently large number of customers in the German demonstrator was crucial to ensure the success of the project. Without a large and diverse portfolio of participants the field tests carried out under the three use cases could not deliver the quality of results.

Following the pre-selection process Avacon reached out to customers directly via mail. Customers were addressed individually and informed that they had been pre-selected and were now invited to participate in the German demonstrator of Interflex, funded by the European Commission and part of a Europe-wide Smart Grid project for our energy future.

To streamline the customer acquisition process as much as possible and to limit the efforts for customers to get on board Avacon opted to invite customers to participate in Interflex by accepting terms & conditions of field test participation in Interflex. The terms & conditions set strict boundaries for the field testing phase and allowed customers to easily decide whether or not they could accept the interference of the Smart Grid Hub field testing with their device.

Once customer had indicated their willingness to participate and had accepted the terms & conditions they would enter a one-sided contract with Avacon for the purpose of carrying out the use cases demonstration of Interflex. The decision whether or not they could actually be a part of the demonstrator would depend on the technical suitability of their device and electrical installation.

For technical reasons, not all potential pilot customers could participate in Interflex. To become a pilot customer in the German Demo, the customers' device had to have an interface to interact with the control box solution employed in Interflex. Furthermore, there had to be sufficient LTE-signal coverage at the customer's premise and inside the house at the meter's location. Avacon has pre-prioritized customers based on coverage data provided by communication network providers. Unfortunately signal strength indoors the could deviate significantly from the outdoor coverage data, which made it a requirement to double check the signal strength on premise to make a final decision.

For the final technical evaluation and selection Avacon clustered the potential pilot customers into 4 groups. The 4 categories are customers that were:

1. Customers that were important to ensure a heterogeneous portfolio of devices participating in the demonstrator, but which required an individual solution for their

connection. These devices were for example battery storage systems, electrical heaters and heat pumps, hot tap water boilers.

2. Devices that were already equipped with a radio- or ripple-control receiver.
3. PV-generators that fell under Germany´s "70%-rule"[1]. These did not necessarily have the communication interface to receive external control signals and required brand and model specific installation solutions.
4. All other devices. In this category fell customers that were operating a device that could only be connected to the Interflex demonstrator with significant alterations of the customer's installation. These customers were de-prioritized due to the comparably high costs and efforts required to integrate them into the Interflex set up.

Table 3 shows the shares of each category.

Table 3 – Number of customers per category for technical evaluation

Category	Number of customers
1	45
2	158
3	151
4	8
Not specified	4
Total	**366**

Once the final selection took place and customers were officially accepted as participants, Avacon sent an official letter announcing the start of the field test phase and participation of each customer.

4.2. Lessons Learned on Customer Acquisition

Generally speaking, the customer engagement in the German demo can be considered a success. Before the consideration of technical limitation imposed by the customers individual installation and networks coverage data Avacon outperformed the ambition level of 200 participants by 166. The successful customer engagement can be attributed to a number of factors.

First of all, many customers reported that they were interested in opportunities to contribute to fighting climate change and to support a sustainable energy supply. A majority

[1] Owner of PV generators under 30 kWp have a legal obligation to either equip their PV generator with a device to enable remote control by the DSO or else limit their maximal output to 70% of nominal power rating. See Renewable Energy Law (2017) §9 (2) 2.

of participants and interested parties exhibited a sincere interest in environmental issues and a wish to contribute to Germany's energy transition. For these customers bulk supply and centralized generation came with a negative connotation. On the contrary, the idea of increasing one's share of local supply and supporting decentralized models of energy supply was received positively. The idea of playing an active role in enabling regional and local power supply was very appealing to pilot customers. Highlighting these aspects in the project's communication played a big role in the successful turnout of customer acquisition.

Beyond the general theme of sustainability and green energy supply, some customers also found it interesting to be part of a bigger project on the European stage. The idea of their participation contributing to a joint project on a European level was of relevance was mentioned by some customers as the reason for their participation.

Another factor to contribute to the customer acceptance was the availability of a state-of-the-art metering equipment at no additional costs. Once the deployment of smart meters begins, certain groups of customers will receive an obligatory smart meter and will be charged an increased meter service fee. Because of this increase in costs, which can amount to 100€ per customer and year, the public acceptance of the smart meter deployment is still relatively low. InterFlex was operating real smart meters according to specifications but did so before the official rollout had commenced. This allowed Avacon to waive the increase in costs for the duration of the pilot project. Customers appreciated the opportunity to try out the new device without having to commit to the increased costs that would otherwise come with it.

5. OVERVIEW OF USE CASES AND KEY INSIGHTS

5.1. Use case 1 – Smart Curtailment

5.1.1. Legal and regulatory framework for smart curtailments of DER in Germany

The legal basis for Use Case DE1 is given in the renewable energy act ("Erneuerbare Energien Gesetz" or "EEG"). §12 EEG states that grid operators are obliged to connect all sources of renewable energy to their network at request and ensure that their network offers enough hosting capacity to accommodate all energy that is produced under the EEG. This includes the obligation to optimize, expand and reinforce the network whenever necessary. If the grid capacity is temporarily insufficient, §14 EEG enables a curtailment mechanism which allows grid operators to temporarily reduce the feed in by DER to maintain safe and stable operation. When curtailments are carried out, owners of DER qualify for financial reimbursements which are recovered via the grid operator's grid charges. The obligation to increase grid capacity remains nonetheless.

5.1.2. Common Scenarios to Trigger Curtailments

In practice, this curtailment mechanism is triggered when a grid operator identifies a critical situation and has exhausted all other options to bring the network back to normal. TSO and DSO can trigger the mechanism alike, if the TSO owns the congestion it can request underlying DSO to reduce feed-in on relevant lines and substations accordingly. Common scenarios to trigger a curtailment are for example:

- Overloading of powerlines in the VHV system
- Overloading of transformers connecting HV and VHV networks
- Overloading of powerlines in the HV system
- Overloading of transformers connecting HV and MV networks

The curtailment mechanism is rarely triggered by events below the HV/MV-substation because of a lack of monitoring and control capabilities in these networks. In the future technologies like the Smart Grid Hub in combination with a Smart Meter + Control Box infrastructure can enable curtailment mechanisms on the MV and LV level, which may even react to a violation of voltage bands.

5.1.3. Shortcomings of present approach and room for improvement

The present approach is based on legacy technologies. The system we find today in many networks is based on long-wave radio signals and ripple control. The control command from a DSO is handed over to a communication service provider who broadcasts the signal via a radio signal across the entire service area. With this, the signal can be communicated over long distances without the need to install additional communication infrastructure apart from a signal receiver on the customer's premise. There are however significant drawbacks to this technology. For example, the radio receiver is limited to four discrete setpoints, it can only limit the generator to 0%, 30%, 60% or 100% of its nominal power output. It is also limited to transmitting signals from the DSO to the customer's device, lacking a backchannel over which the DSO could acquire additional data or confirm the successful reception of the control signal. This means that DSOs have no backchannel to confirm whether their signal has been acted upon and can neither identify faulty or malfunctioning receivers. The technology also requires setting the address parameters offline at the customer's device and does not allow for dynamic addressing or remote updating. This leads to the practical limitation that large numbers of DER must be aggregated for control purposes. This creates a suboptimal setup which leaves room for improvement.

With the development of the SGH InterFlex aimed at providing the technological basis to improve on these shortcomings. Use case DE1 has demonstrated a smart curtailment management that enabled individual addressing, the flexible aggregation of clusters of DER and a backchannel which allowed for command confirmation and the acquisition of additional data points to better estimate the state of the grid.

5.2. Results of field testing

InterFlex did extensive testing on the application of a smart curtailment mechanism in the field testing area around Lüneburg. Following a step-by-step approach, the goal was to confirm the feasibility of the envisioned control strategy, to determine reliability and speed of command execution and build a data base to decide on the practical relevance of the approach. Test procedures were designed from simple tests with few elements to tests of increasing complexity and numerous elements.

5.2.1. Test 1 - Switching of single generators & groups of generators off-load

Test Overview	
Title	Off-load switching, single & multi
Type of elements activated	PV
Number of elements activated	3

The goal of Test 1 was to carry out fundamental switching actions on individual devices and groups of devices to confirm the basic functionality of the systems and interfaces involved. The test was carried out four times in total, with 3 out of four showing only one successful activation. After fixing a potential source of error, all activations were carried out successfully and were displayed correctly in the SGH GUI.

Table 4 - Evaluation of Test 1

	Attempted Connections	Successful activation	Number of Connection Losses (KPI2)
Trial 1 (Off-load, single)	3	1	2/3
Trial 2 (Off-load, multi)	3	1	2/3
Trial 3 (Off-load, multi)	3	0	3/3
Trial 4 (Off-load, multi)	3	2	1/3
Total	12	4	8/12

5.2.2. Test 2 - Reliability of communication

Test Overview	
Title	Reliability of communication
Type of elements activated	PV
Number of elements activated	19

The aim of Test 2 was to quantify the reliability of the communication link between SGH and flexible devices. The basic test set up was to combine all elements which were available at the time of testing into one group and then request an ad-hoc measurement for this group. The test was initiated ad-hoc at 12.37pm and carried out immediately. Shortly after the test was interrupted with errors. Results showed that of 19 elements that should have been online only 11 provided data.

Table 5 - Evaluation of Test 2

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)
Trial 1 (Measurement, single)	19	11	8/19

5.2.3. Test 3 – Multi-Switching Requests

Test Overview	
Title	Multiple Switching Requests
Type of elements activated	PV
Number of elements activated	19

The objective of Test 3 was to quantify the performance of the SGH architecture under higher workloads. In its first iteration Test 3 would request different switching commands from a group of generators at intervals of 10 minutes. The requested flex activation would be to cap power production at 60%, 30% or 0% of nameplate rating. The tests were carried out between 6 pm and 6.30 pm. The second iteration would reduce the time between commands to 1 minute. The second iteration was scheduled between 9 pm and 9.20 pm.

The results were mixed, all tests were completed but with errors.

1. In both iterations one generator was not responding, neither transmitting meter data, nor carrying out flex requests.
2. Despite all requests being carried out eventually the SGH did not stick to the initial sequence of the scheduled commands.
3. There was a noticeable gap between the time a command was scheduled and when it was carried out.
4. Commands were not carried out in parallel, but strictly in sequence.

The second run of Test 3 aimed at probing the ability of the SGH to control several groups of flexible elements in parallel. The test set up required the SGH to switch off the generators in different substations at roughly the same time and to reset to 100% power output 1 minute later. To minimize the risk of unnecessary curtailments these early tests were scheduled for non-production time of day at 9 pm. The results were positive, the switch-off command was transmitted at 9.01 pm and confirmed by 14 of 16 elements. Subsequently the switch-on command was transmitted between 9.30 pm and 9.44 pm and received by 12 of 16 elements.

Table 6 - Evaluation of Test 3

	Attempted Connections	Successful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, multi)	16	15	1/16	< 60 sec	1/min
Trial 2 (Off-load, multi)	16	15	1/16	< 60 sec	1/min
Trial 3 (Off-load, multi)	16	14	2/16	< 60 sec	1/min
Trial 4 (Off-load, multi)	16	12	4/16	< 60 sec	1/min
Total	64	56	8/64	< 60 sec	1/min

5.2.4. Test 4 – Local Schedule Override

The control box solution is capable of storing schedules offline. In the future advanced use cases could go beyond ad-hoc commands and deploy schedules for flexible elements hours, days or even weeks ahead.

The aim of Test 4 was to set a predefined schedule for a single device and then override the schedule with SGH commands. The schedule for a full week was set to full feed in from 4 pm to 2 pm and “off” from 2 pm to 4 pm every day for a week. To test the override function the operator would set the generator to full feed in after 2pm and check whether the device fed in or stayed off. In the first trial the schedule was transmitted successfully, but the control failed to carry out the planned schedule. Figure 4 shows a screenshot of the SGH UI in scheduler mode.

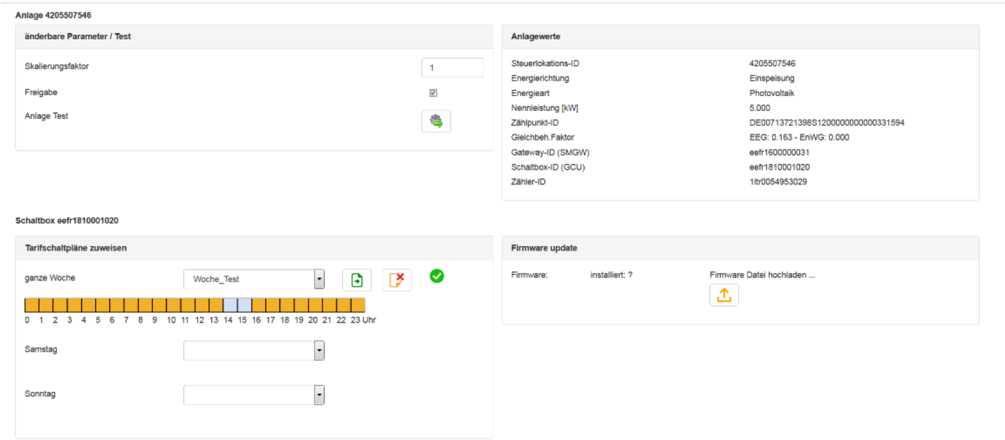

Figure 4 - SGH UI Scheduler

The planned schedule, which set the generator output to 100% from 5 pm to 3 pm and to 0% from 3 pm to 5 pm, was transmitted successfully. The operator then scheduled a request for full production starting at 4 pm, to override the 0% schedule starting at 3 pm, and added another request for 1 hour 0% starting at 4.30 pm, overriding the scheduled switch from 0% to 100% at 5 pm. Figure 5 shows the planned schedule and override commands for trial 2.

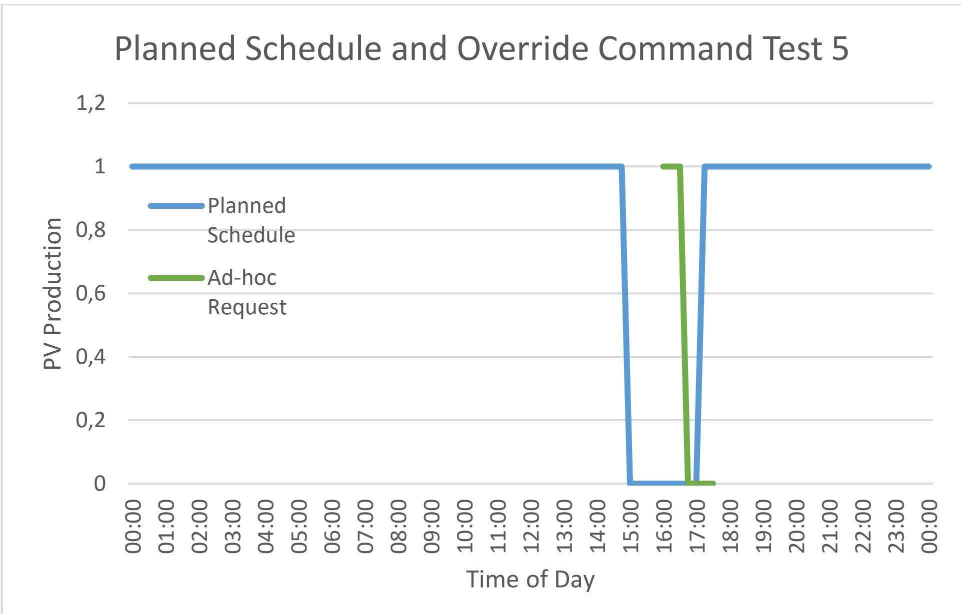

Figure 5 - Planned Schedule and Override Command Test 5

This time the schedule was carried out as planned, reducing the power output to 0% at 3 pm. The following attempt to override the scheduled 0%-limitation with a request for full power was not successful. Further the schedule would have been followed to de-limit production at 5 pm, however the override command to extend the limitation to 5.30 pm was successful. Figure 6 shows the resulting data from trial 2. The diagram clearly shows the sudden limitation of power output to 0% beginning at 3 pm / 15h. The production does not ramp up when the 100% command is supposed to override the schedule. Later production does not ramp up at 5 pm / 17 h as per schedule, but waits until 5.30 / 17.30 h as per ad-hoc command.

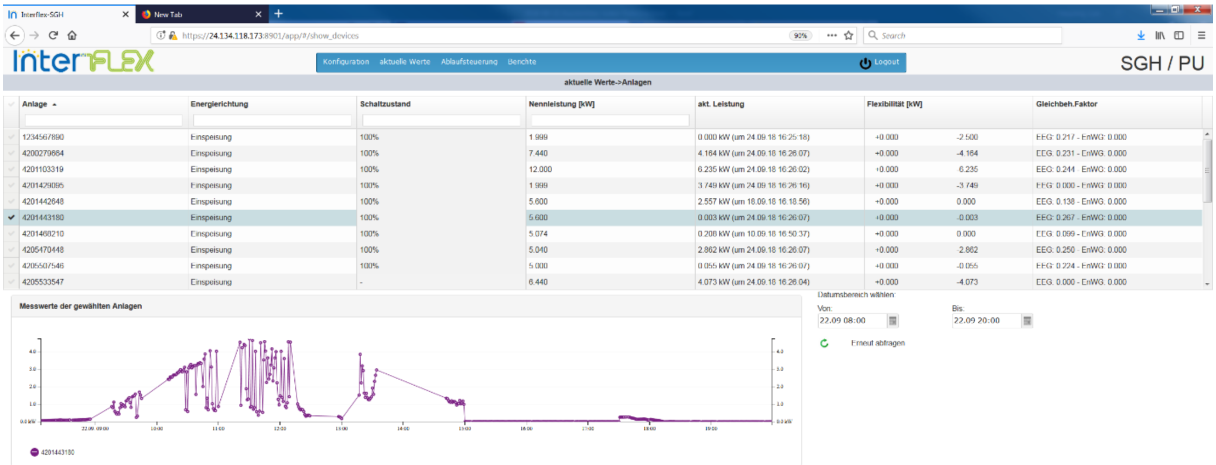

Figure 6 - Results of Test 4 Trial 2

5.2.5. Test 5 – On Load Switching of Single Elements

Test Overview	
Title	On-load switching, singles
Type of elements activated	PV
Number of elements activated	19

For this test a single generator was to be switched off and switched on again during daytime with good power production conditions. Establishing the Controllable Load System (CLS) channel over which the control and metering data is transmitted was not part of the drill, the CLS channel itself was established beforehand.

Generator 4201443180 was switched off at 1.27 pm, the command was confirmed almost immediately. Less than 60 seconds later the next set of measurements confirmed the successful switching. The command to de-limit the generator was communicated at 1.31 pm and confirmed almost immediately. The next set of measurement confirmed this less than 60 seconds later.

Table 7 - Evaluation of Test 5

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, single)	1	1	0	< 60 sec	1/min

5.2.6. Test 6 – On-Load Switching of Multiple Elements

Test Overview	
Title	On-load switching, multiple
Type of elements activated	PV
Number of elements activated	13

Test 6 replicated the prior test 5 but instead of a single element the aim was to control a group of flexible elements. To ensure that the command showed a measurable effect the tests were scheduled to a time of the day when power production was high. During the test window between 1 pm and 2 pm all 13 elements were online and power-producing.

At the beginning of the test the command “Limit to 0% power output” had been assigned to the group of elements. The command signal was confirmed almost immediately at 1.41 pm, evidently so by the next set of measurements less than 60 seconds later. At 1.45 pm the command to de-limit power production was transmitted and confirmed almost immediately.

Table 8 - Evaluation of Test 6

	Attempted Connections	Successful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, multi)	13	12	6/13	< 60 sec	1/min

5.2.7. Test 7 – Detailed Breakdown of Time Steps

The switching and metering of flexible assets via the Smart Grid Hub is a sequence of several discrete actions. The exact timing and duration of these steps are not visible to the SGH operator. To have full visibility on these details however a test application had been developed that gave testers and operators a deeper insight into the inner workings of the system for the following actions:

1. Retrieve most recent meter data from data base (METER1)
2. Establish CLS channel (CLS CONN)
3. Switch Generator (SWITCH EEG)
4. Close CLS channel (CLS DISCONN)
5. Retrieve the next meter data point after switching (METER2)
6. Time used to access external data base (EXTERN)

The time step breakdown protocol has been executed with 8 flexible elements using the test application. Table 9 shows the results for each time step for each individual tested element,

Table 10 shows the overall maximum, minimum and mean value for each step of the process.

Table 9 - Detailed Time Step Breakdown per Unit

#	Meter 1 [ms]	CLS Conn [ms]	Switch EEG [ms]	CLS Disconn [ms]	Meter 2 [ms]	Extern [ms]	Total Duration [ms]
1	300	92537	928	17076	5452	486	116779
2	317	82501	311	18801	14314	138	116382
3	309	84912	887	18415	10529	1135	116187
4	297	91714	419	17508	5706	821	116465
5	303	90259	207	18052	6495	1486	116802
6	317	94607	170	18709	2902	170	116875
7	315	97977	157	32908	45466	1802	178625
8	317	82197	525	19508	12748	211	115506

Table 10 - Overview Detailed Process Step Duration

	Min	Mean	Max
Meter1	297	309	317
CLS CONN	82197	85588	97977
SWITCH EEG	157	450	928
CLS DISCONN	17076	20122	32908
METER 2	2902	12951	45466
EXTERN	138	781	1802
TOTAL	115506	124202	178625

Overall the meter-switch-meter use case took between 115.506 and 178.625 milliseconds (1,92 to 2,98 minutes). In each case the most time-consuming step was to establish and close the CLS channel, a process that requires several checks of access rights and certificates and which involves the gateway administration service. Without the necessity to establish the CLS channel first and then close it once the action has been carried out the performance of a use case can be shortened by 100 to 130 seconds, an improvement on overall time of 73% to 97%.

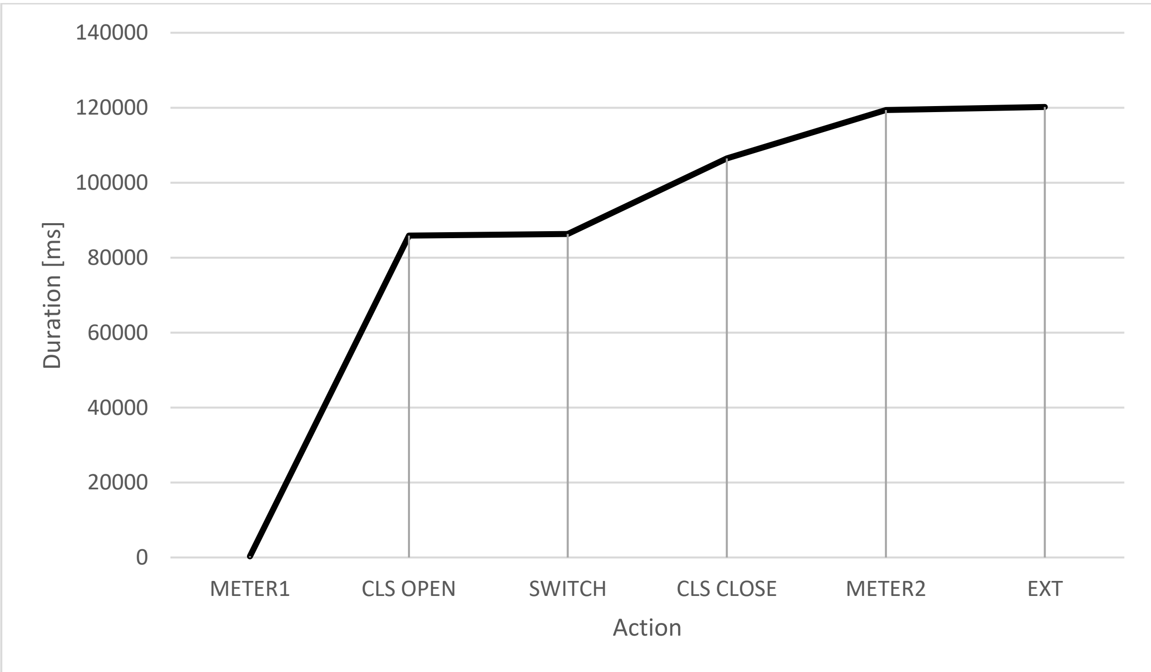

Figure 7 - Duration for Individual Steps in a Switching Action

5.3. Lessons Learned on Use Case DE1 - Smart Curtailment

The extent of connection losses per trial was a main concern. Insufficient mobile network coverage accounted for most of these connection losses but likely not all of them. During InterFlex it could not be determined with certainty what other reasons could be contributing to this issue. At this stage, the reliability of the communication link between flexibility and SGH remains a concern for a full production implementation and is not up to grid control standards. The introduction of powerline communication as an alternative mode of communication could help stabilizing the data link. PLC had been tested late in the project and first tests have confirmed the hypotheses that it can provide a more stable data link in areas where mobile network coverage is lacking. However, PLC is more expensive because it requires an additional data concentrator at the nearest substation and relies on a relatively high penetration of PLC-equipped customers.

Test 3 highlighted weak spots in the current architecture to be investigated further. In part, these issues could be traced back to the communication uplink via the mobile network. Other parts appear to relate to the performance of adjacent IT-systems (e.g. the gateway administration service) and the internal workings of the Smart Grid Hub itself (e.g. command being carried out strictly in sequence).

It is noted that the control of different groups even in short sequence does not pose a problem. As the first run of tests showed the SGH struggles to perform the switching of individual elements with high frequency.

5.4. Use Case 2 – Ancillary Services

Use case DE2 is described in the Grant Agreement as follows:

“Ancillary services (for instance balancing energy) may come from the aggregation of generation, consumption and storage devices. The signals sent out for ancillary services have to be coordinated with other signals such as the ones for curtailment or demand response. The security and speed of data transmission as well as the speed of command execution and the respective confirmation signals are crucial.”

The paragraph above comes down to three key goals for the execution of use case 2 demonstrations:

a. Demonstration of aggregation of generation, consumption and storage devices
b. Coordination of ancillary service requests with higher-ranking control signals
c. Evaluation of communication systems performance

Due to external dependencies and the unavailability of technical system in the smart meter environment (out of scope of InterFlex and at the time proposal submission expected to be ready by the start of field testing), WP5 had to direct a lot of resources towards making the smart meter framework work and making flexibility of different types available in the first place. This shifted the focus of WP5 from evaluating the performance of specific and complex use cases towards developing and demonstrating the technical feasibility of simpler use cases.

In the case of use case DE2 the main condition is the availability and controllability of generation, consumption and storage devices. While the capabilities to control DER and flexible loads have been successfully demonstrated in use case demonstrations DE1 and DE3, the question of storage devices remained open. In part because the regulatory framework did not clearly define the rules for flex activation from batteries, and also because the technological basis was not yet available to control batteries through the smart meter.

This left for use case DE2 to imagine a concept to aggregate flexibility of a higher grade from what has been made available in use case DE1 and DE3.

In this sense, use case DE2 has been carried out with the following questions in mind:

a. What flexibility is available for aggregation?
b. What are the barriers to increase the available flexibility?
c. What are potential implementations?

5.5. Analysis of available flexibility

Among the many potential sources of flexibility, we could differentiate between what is readily available today, provided by existing flexibility mechanisms, and what could only be activated once changes in the regulatory framework have been implemented. While the use case demonstration DE1 and DE3 have shed light on the behaviour of uni-directional flexibility, DE2 was looking into the possibility of creating bi-directional flexibility from subsets of uni-directional devices.

For the purpose of highlighting the results and learnings during use case 2, we have picked a group of customers that reflects the most common types of flexibility that are at the DSO's disposal today in Germany. To demonstrate key insights, we are looking at the data set generated by 2 heat pumps, 2 PV generators and 1 storage heater. Data sets for this analysis range from February 2019 to May 2019, a period in which we would expect to see significant load as well as production.

Table 11 - Sources of flexibility in UC2 field test

Customer #	Type of device	Rated power [kW]
…3616	Storage heater	36
…1105	Heat pump	6
…6812	Heat pump	3
…9095	PV	6
…3319	PV	2

Table 11 shows the rated power and type of the customers. To evaluate the available flexibility, we assumed that all devices could be switched off at the DSO's request for at least 15 minutes at a time[2]. As had been demonstrated in previous field tests in WP5, these general switching capabilities had been developed successfully and the regulatory framework enabled control of these devices by the DSO. Under these conditions we defined the available bi-directional flexibility at any point in time, as the amount of generation and demand that's online simultaneously.

$$P_{Flex,bi-directional,t} = Min\left(\sum P_{Load,t}, \sum P_{Generation,t}\right) \qquad (1)$$

In other words, bi-directional flexibility from uni-directional sources always amounts to the power that is being generated and consumed simultaneously by these subsets of devices. Figure 8 shows the entire data set of heat pumps, storage heaters and PV. The profile is dominated by the 30 kW storage heater installation, which dwarfs the consumption by heat pumps and to a lesser extent also the feed-in from PV installations. However, at first glance it also appeared that during the transitional phase in the European meteorological spring there can be a significant overlap between PV generation and load in the heating segment. We can identify a period of very low solar production in March but see solar production slowly ramping up as the year goes on. Consumption data showed, at least in terms of peak demand, a surprisingly constant behaviour until the first period of warm weather with ambient temperatures during the day of 25°C in late April.

Figure 9 exhibits the practically available flexibility if the DSO would combine interruptible loads and decentral generation to a source of bi-directional flexibility. As expected, the controllable flexibility is much less than the production and load that's online at any given point in time. It also shows that aggregating flexibility requires a delicate balance between

[2] This assumption simplifies the way storage heaters can be controlled.

weather fair enough, so that solar production is online, and temperatures cool enough so that domestic heating still shows significant demand. In the considered period the 1st of April for example stands out as day with a high flexibility offer. Figure 10 visualizes that this day was relatively cold (-0,5°C) and had a relatively high solar radiation (2540 J/cm²) compared to other days in the respective period.

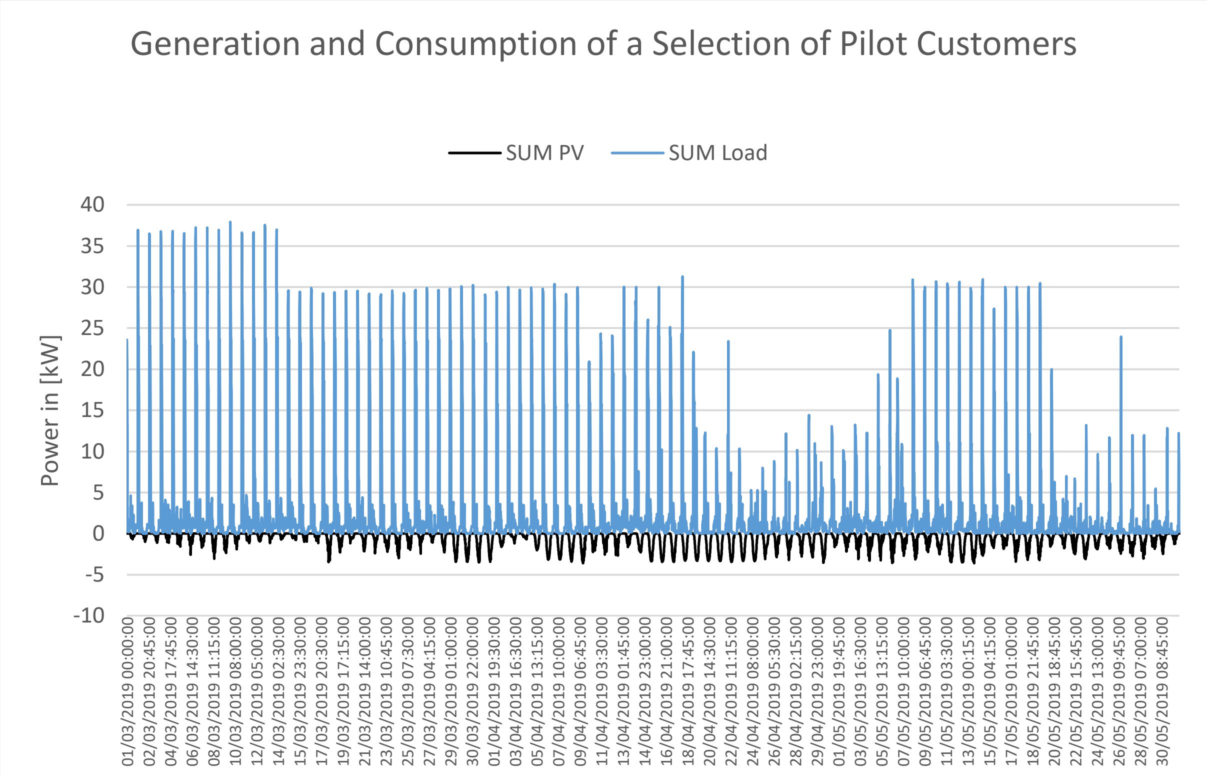

Figure 8 - Generation and consumption data of field test customers

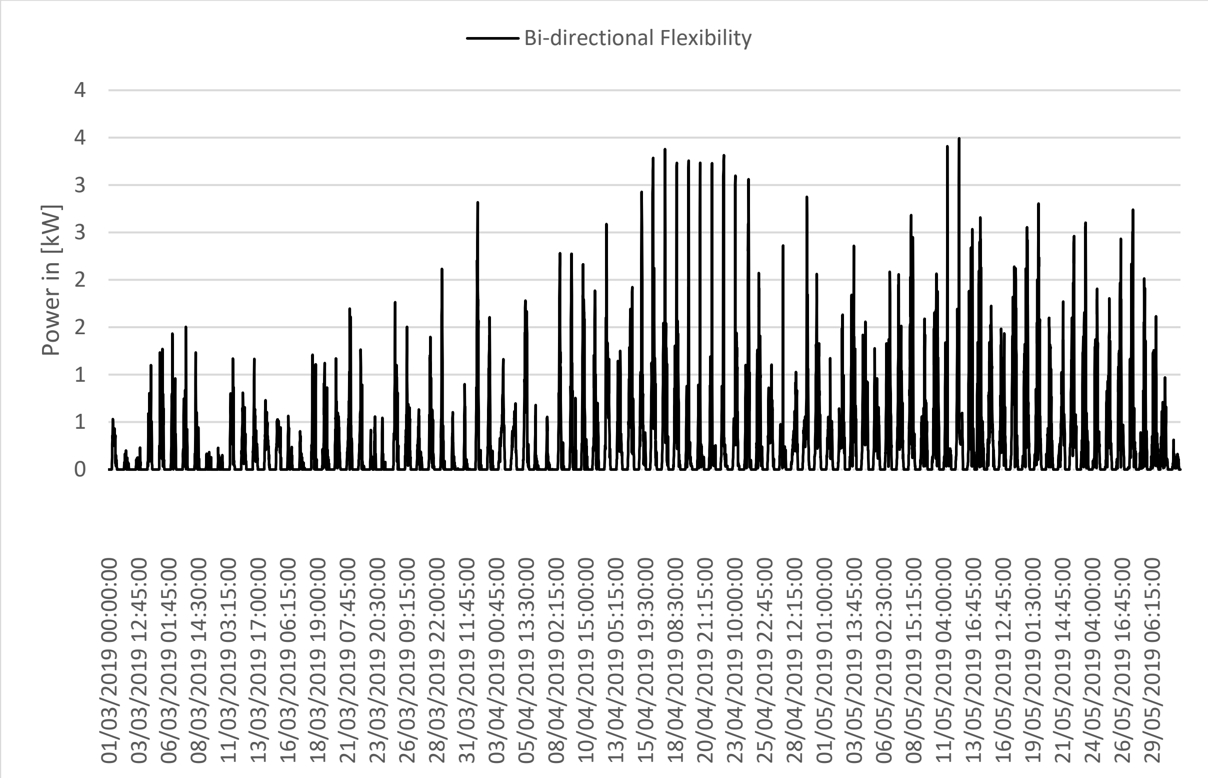

Figure 9 - Available bi-directional flexibility on 15-min basis

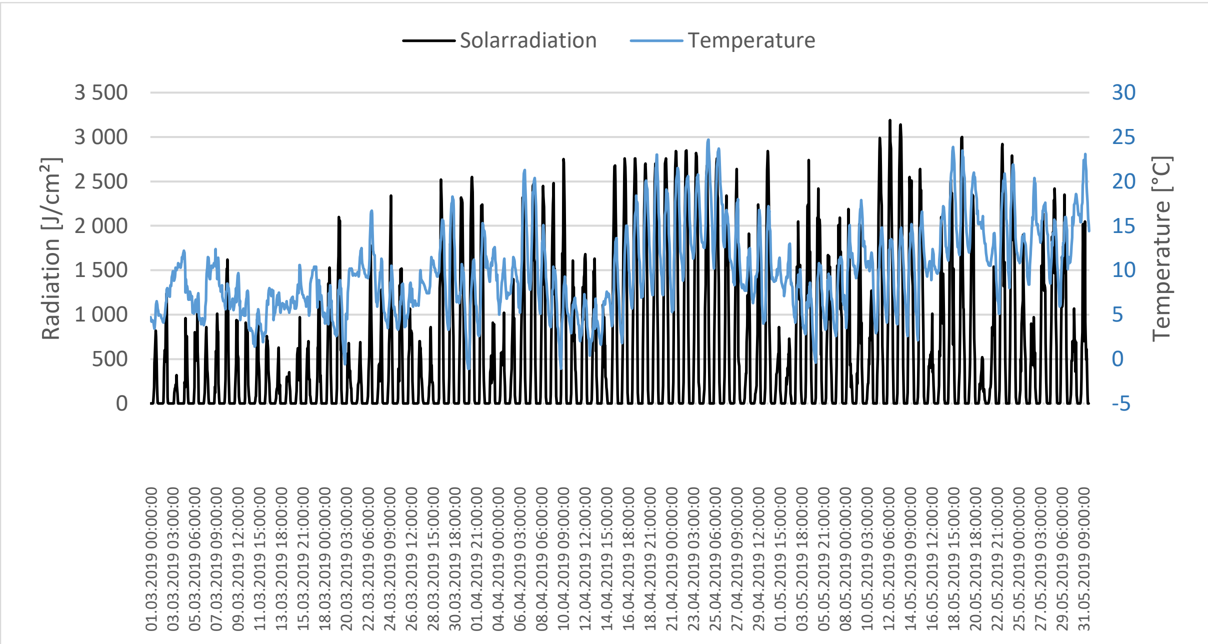

Figure 10 - Solar Radiation and Temperature on hourly Basis

What share of online generation and demand could be diverted to a flexibility mechanism at any point in time? One way to quantify this amount would be to calculate the ratio of available flexibility to the available generation and demand at that point in time. Looked at it this way, 57% of the time (4558/8743) the available flexibility equals 5% or less of online production and demand. In only 2% of the observed data points did the available flexibility amount to more than 95% of online generation and demand. For further illustration, Figure 11 displays the entire data set sorted by the amount of available flexibility. Even keeping in mind that this is a fairly small sample in a small geographic area it is still clear that the flexibility aggregated from uni-directional sources must be expected to be much less than the individual power rating and production of the aggregated elements.

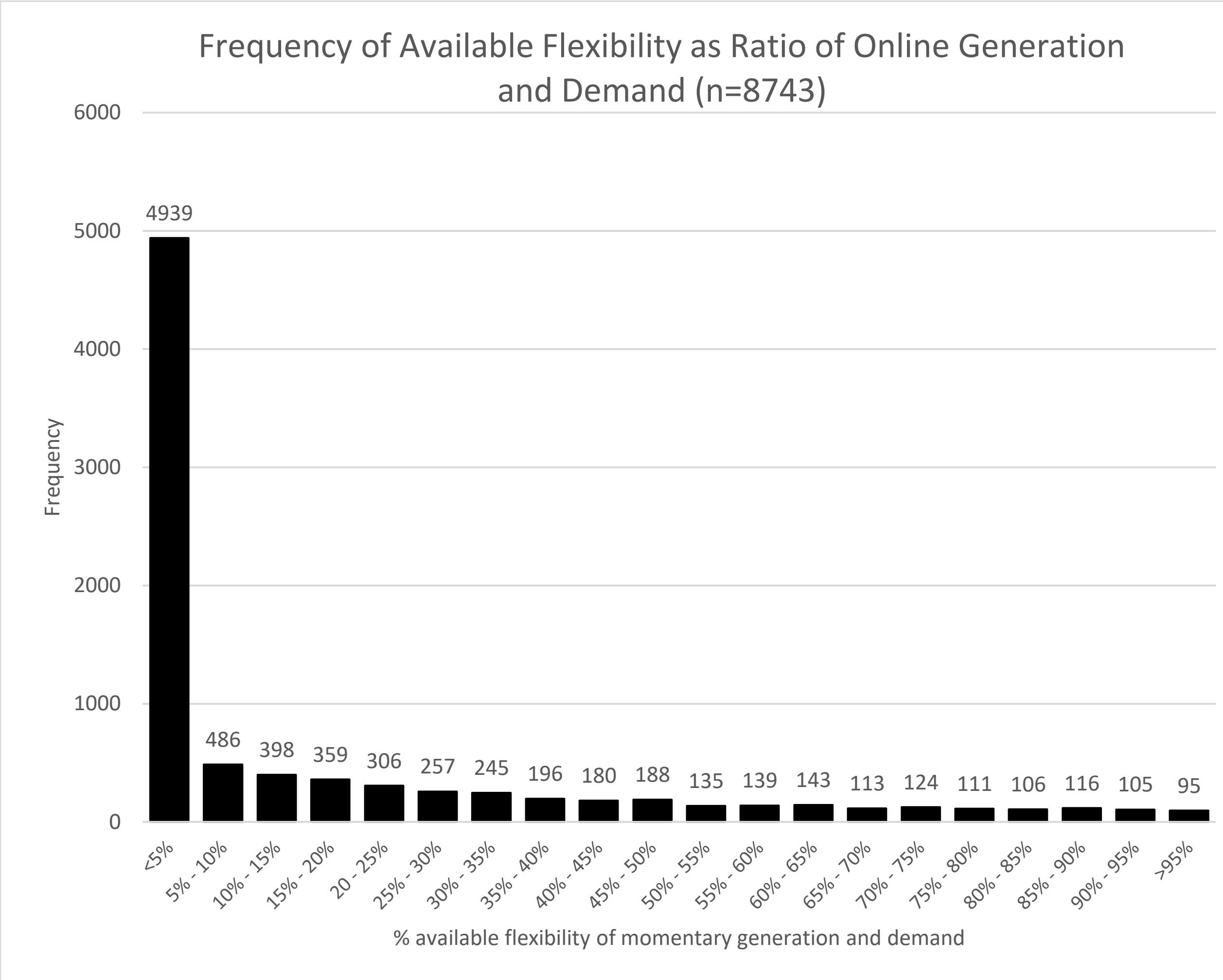

Figure 11 - Available bi-directional flexibility as % of momentary generation and demand

As we have seen, the share of flexibility from the overall generation and demand is fairly low. During the testing period PV generators produced a total of 5,131.51 kWh, the demand in domestic heating during the same period amounted to 25,216.5 kWh[3]. The total available

[3] The storage heater was vastly overdimensioned, serving a larger living facility for the elderly.

flexibility during that period was 2,174.3 kWh, 8.6% of the total demand and 41% of the total generation[4].

Taking a closer look at relevant scenarios show further how the different technologies interact and overlap. For example, in early March we saw a period of bad weather with low temperatures and little solar radiation. During these times, uni-directional flexibility increases due to high demand in domestic heating, bi-directional flexibility however is reduced significantly due to the lack of solar radiation. Figure 12 displays the data for the days in early March. We see the demand in domestic heating, particularly the big storage heating installation, dwarfing solar production. In addition to this, we can also see that the peak in load and generation are almost perfectly set apart.

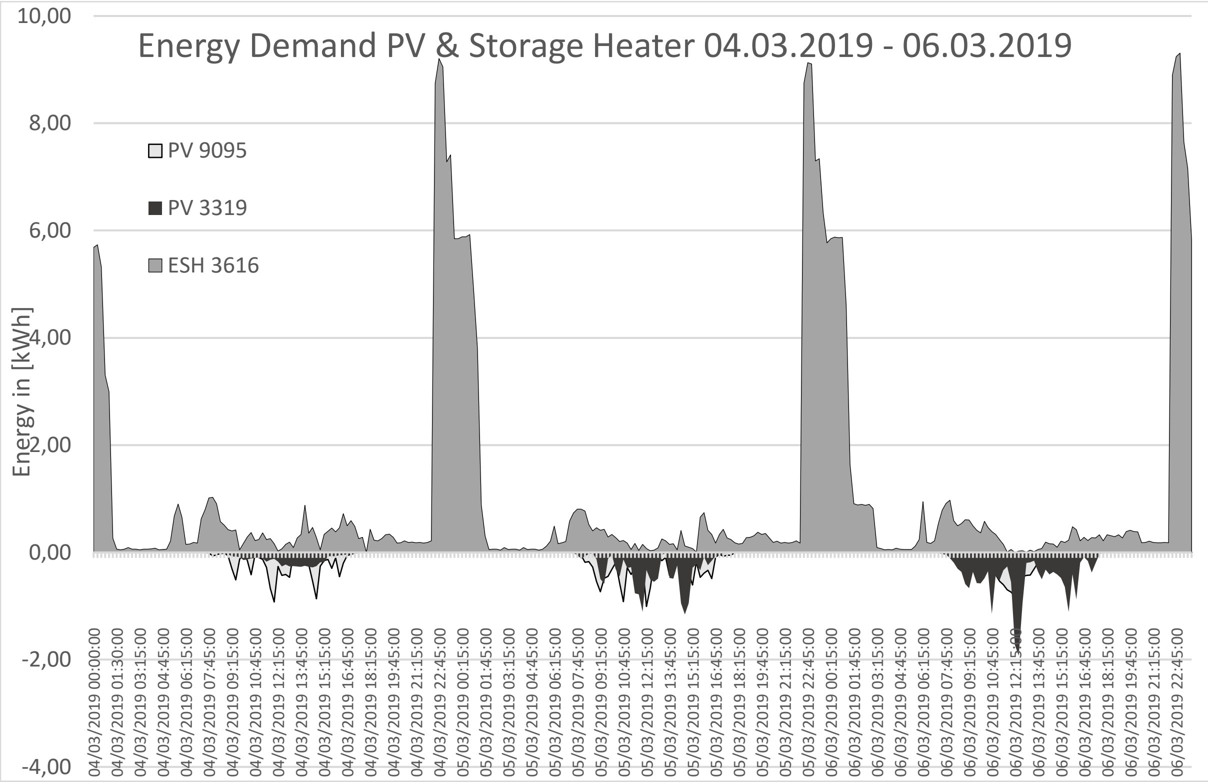

Figure 12 - Comparison of domestic heating demand and PV production 04.03. - 06.03.2019

If we take a look at the opposite scenario, times of high solar production and comparably lower domestic heating demand, we see a different situation. Here the demand in domestic heat does not outweigh solar generation as much. The time shift between the two however

[4] This also means, that in this scenario theoretically 41% of local generation has already been consumed locally.

remains. A large amount of potentially useful flexibility is being wasted when storage heaters remain limited to charging at night.

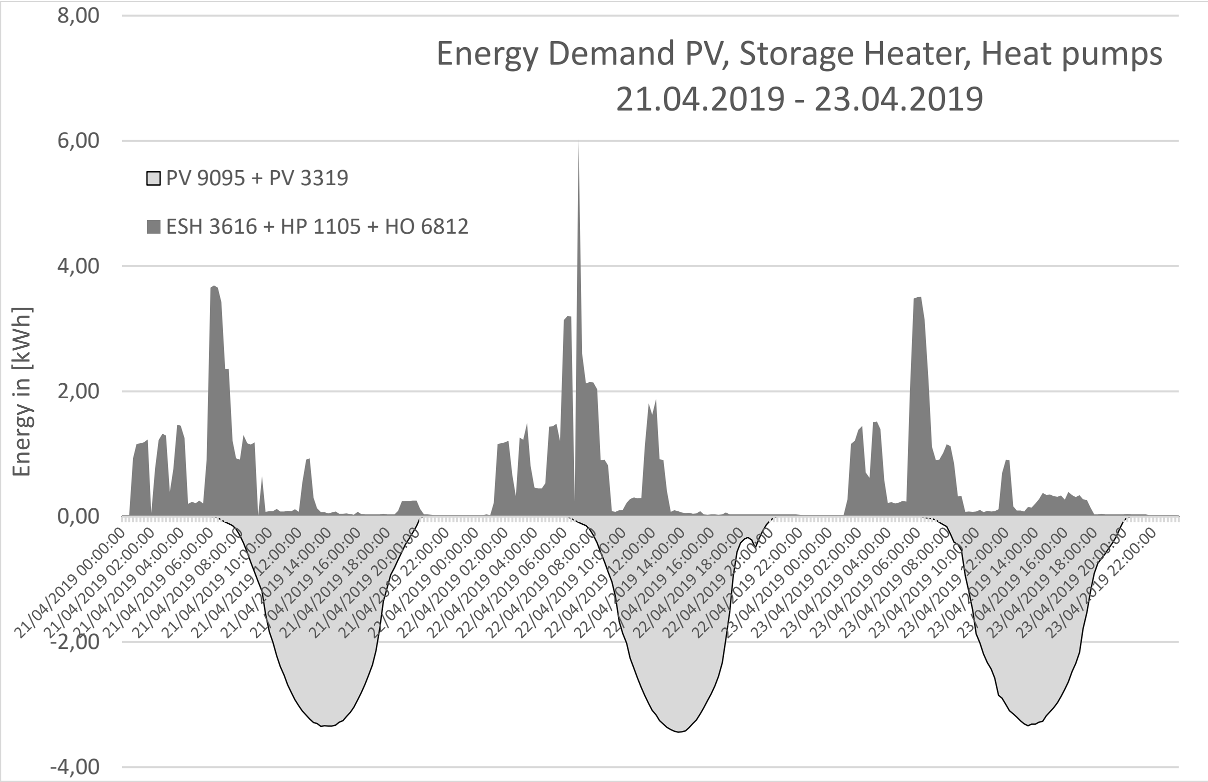

Figure 13 - Comparison of domestic heating demand and PV production 21.04. - 23.04.2019

5.5.1. Lessons Learned Use Case 3 – Ancillary Services

Over the course of use case 2 demonstrations and the subsequent analysis of data we could see that there is potential for additional bi-directional flexibility in today's distribution networks. This is an important finding, as it can encourage DSO to start activating and using these flexibilities for the benefit of the network. All it takes is a control- and metering infrastructure such as the one Avacon has developed and demonstrated in the German demo.

The available bi-directional flexibility that can be aggregated from uni-directional sources is less than the total amount of generation and momentary load. How much flexibility can be made available at any given point in time is depending on the type of devices offered by customers, the time of the year and time of day as well as meteorological factors like ambient temperature and solar radiation. Especially in the transitional months during spring and autumn when solar generation is online and coincides with demand from domestic heating, we can find significant contributions to the available flexibility in low voltage networks. This flexibility could be directed for example to prevent grid congestion or to increase the local consumption of renewable energy.

There are ways to increase the amount of available flexibility. For example, adding ESS, EV an EVC to the concept would bring more flexibility. This additional flexibility would also reduce the dependency on the local weather. Roadblocks for the integration of these technologies are discussed later in chapter 8.2.

5.6. Use Case 3 – Demand Response

Use Case DE3 evaluated the new technology that had been developed to validate new applications and control strategies that would now become feasible. The focus of use case 3 was therefore the control of flexible loads in the residential segment with the goal of improving DSO operations, increasing hosting capacity for DER and higher quality of supply in low and medium voltage networks.

5.6.1. Legal and regulatory context

The directive 2012/27/EU art 15 (4) states that « Member States shall ensure the removal of those incentives (…) that might hamper participation of demand response, (…) » as well as improving customer participation in demand response. In Germany we found these aspects reflected in §14a Energy Industry Act (EnWG), which states that « Network operators are obliged to offer a discount on grid charges for those customers who offer controllability and flexibility to the system operator ». It further states that the details of this controllability and flexibility scheme remain to be defined in a statutory law which is yet to be finalized. Until then however, historic flexibility- and control-mechanisms have been grandfathered in under EnWG §14a.

The most common among these historic control mechanisms is a DSO-controlled switching of storage heaters that once applied to double-tariff customers. This kind of customer would receive a discounted energy tariff during off-peak hours. These tools were conceived in an era before the German energy system underwent unbundling, so back then the discount would apply on a combined retail- and grid charge price. The distribution company would determine the discount and retain control over the definition and switching of peak and off-peak windows. Today retail and grid are unbundled so that the retail share of a customer's energy does not necessarily reflect the old double tariff model. However, under §14a EnWG the grid operator is still granting a grid charge discount in exchange for controllability and is still using the same systems to carry out the tariff switching, even though it might not have any effect on the retail side. The contractual agreement states that the DSO defines preferred charging times, guaranteeing a sufficient number of hours to cover customers energy demand. In practice, DSO usually have fixed charging windows during the night that amount to 8 hours of charging time. During these hours the customers heating device would charge up with thermal energy and release the heat throughout the following day. On particular cold days and in some regions, DSOs might also activate heaters for additional heating periods during the day to cover high demand.

Heat pumps on the other hand have not been around in large numbers when the first installation of the double-tariff scheme took place in the 60s and 70s, so they are less burdened with historic flexibility mechanisms. Taking into account customer's expectation for comfort and the capabilities of the devices, today's agreement between DSO and customer under §14a EnWG states that Avacon has the right to interrupt the heat pumps operation for up to 2 hours, up to 3 times per day.

5.6.2. Technological aspects and controllable devices

There are three commonly used technologies to carry out the control actions described above.

First, there are clock timers installed locally on the customer's installation. These simple devices open and close the charging windows for storage heaters at fixed and predefined times each day, independent of temperature, load or other grid considerations. This simplest of all technologies has no communication, no online data and cannot be accessed or modified from the outside. Customers equipped with clock timers do not offer flexibility.

Secondly, we find load control via long wave radio signals. Here customers are equipped with a long wave radio receiver that switches devices on or off according to the current status of the signal. The sender is owned and operated by a third party and not part of the DSO infrastructure. This system does not provide any live data or signal confirmation.

And lastly, some grid operators employ acoustic ripple control to carry out load control. The senders are owned and operated by the DSO and often fully integrated with the grid OT. However, the system does not have any advanced data processing capabilities and offers very limited options for dynamic load control. In practice, the system is used to broadcast the same signals day in day out. Signals are only modified by manual intervention when a fault occurs.

What all three systems have in common is a lack of data processing capabilities and that none fits into the smart meter framework. This circumstance makes it impossible to carry out complex use case algorithms and in turn renders the existing flexibility in households useless for the DSO.

5.6.3. Shortcomings of present approach and potential for improvements

Even though both regulatory mechanisms could theoretically offer a fair amount of flexibility to the DSO, the technological limitations prevent DSOs from making use of it. For once, the existing technologies to control these flexibilities are not suited to enable a dynamic and integrated approach to the control of small-scale flexibilities. On the other hand, the uncertainty about future developments of the regulatory framework, particularly the final content of the statutory law concerning §14a EnWG, leaves DSO hesitant to commit resources to design a decision- and control framework that can take full advantage of the target segment. Before InterFlex there was also a lack of suitable technologies that enabled precise, dynamic and transparent control of small-scale flexibilities.

To sum up the shortcomings of the existing approach:

- No or limited possibility to discriminate for location
- No possibility to control individual devices
- Outdated analogue systems
- Limited integration with peripheral IT/OT-systems
- Limited potential to increase degree of integration with peripheral IT/OT-systems
- No potential to integrate with future smart meter systems

This list of shortcomings presents possibilities for InterFlex to improve on the status quo. For example, InterFlex and the Smart Grid Hub:

- Are fully integrated with peripheral IT/OT-systems (Smart meter administration, SCADA / ADMS)
- Are digital systems that enable complex use case algorithms
- Leverage the smart meter framework to enable individual and dynamic control of flexible elements.

The use case demonstrations that followed were designed to investigate the transition between new and old technology.

5.7. Results of field testing

5.7.1. Test 1 – General Switching Capabilities for Storage Heaters

The tests demonstrated how the SGH in combination with a Smart Meter and control box on the customers premise could replace the broadcast or ripple control technology to manage the consumption of double-tariff devices in private households.

Within InterFlex Avacon set out to demonstrate how the SGH can enable dynamic control for the customer segment equipped with heat pumps or storage heaters. The SGH enabled a switching regime that could be adjusted on a daily basis and control different customers each individually. Having these capabilities would enable the DSO to take advantage of the flexibility in this customer segment. Potential upsides include:

- Staggered switching of sub-groups to reduce peak load

- Preventive reduction of remedial actions in high-feed-in scenarios
- Optimized load dispatch to improve DSO economics

To capture these upsides however, the general switching and control capabilities had to be demonstrated first.

Table 12 - Overview of Storage Heater Activations

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	14.04.2019	Modification of Charging Slot (Delay Start 2hr)	3	2/3
2	15.04.2019	Modification of Charging Slot Delay End 2hr)	3	2/3
3	15.04.2019	Modification of Charging Slot (Delay 1hrs)	3	2/3
4	22.04.2019	Modification of Charging Slot (Delay 0.5 hrs)	4	2/4
5	24.04.2019	Load Reduction	4	2/4
6	26.04.2019	Live Data Streaming	4	0/4
7	29.04.2019	Load Reduction	4	2/4
8	29.04.2019	Load Reduction	4	2/4
9	29.04.2019	Load Reduction	4	2/4
Total				**16/33**

During the demonstration period test runs had been executed. To evaluate the function of the storage heater link, a total of 9 demonstrations had been run with groups of storage heating devices.

The rate of success of switching and metering requests never exceeded 67% and was as low as 50% most of the time. While the cause for this disappointing rate remains to be researched, one reason is likely the LTE-connection between the gateway administration service and the smart meter gateway. The weak mobile network signal had been identified as a source of error in previous field tests of other use cases, too.

Figure 14 shows the data of a storage heater customer with successful modification of the customers charging slot. On 14.04.2019 the charging slot was delayed by two hours from 10pm to 12am, on 15.04.2019 it was delayed by one hour from 10pm to 11pm. Both days demonstrate the typical behaviour of a storage heater: a sharp rise of power demand once activated, followed by a reduction in demand in steps when individual devices shut down once their charge has reached a target value. The only difference, as intended, is the time of the start of the charge.

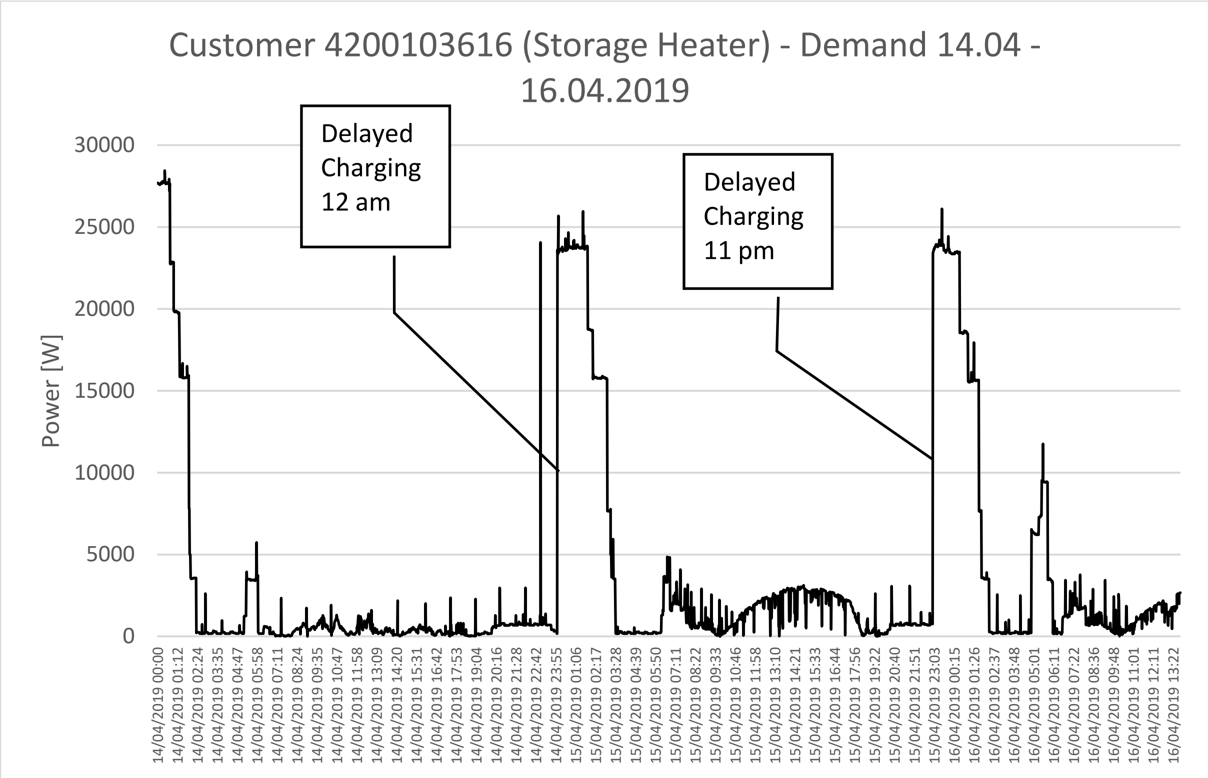

Figure 14 - Charging Slot Modification of Storage Heater via SGH

5.7.2. General Switching Capabilities for Heat pumps

When it came to the addition of more flexibility to the power grid, leveraging thermal inertia of buildings is a good place to start looking. As we saw in 5.7.1, storage heating devices can introduce an element of controllability and flexibility in the otherwise uncontrollable and inflexible segment of residential customers. Storage heating devices however are oftentimes outdated and based on 70’s and 80’s technology. They also leave many customers wanting for more comfort, easier usage and better transparency. New storage heating devices are rarely installed in Germany anymore and the existing pool of devices shrinks per year at rate of roughly 4%. So, while storage heaters can play a vital role during a transitional phase towards a flexible cross-carrier energy system, they are not the last word in sector-coupling in the residential segment. Another technology that is already widely deployed and could potentially offer flexibility are heat pumps. These devices work by extracting heat from the surrounding air or ground by pumping a heat-carrying fluid between two heat-exchanger.

The pumps are driven electrically and represent the only energy consumption of the device to provide heat for the building.

In Germany, heat pumps can qualify for a reduced grid charge if they offer controllability to the DSO. In the case of Avacon, it is contractually agreed that in exchange for a reduced grid charge, Avacon can interrupt a heat pump's operation for a period of up to 2 hours, a maximum of 3 times per day, with a minimum of 1 hour of operation between two interruptions. With this, heat pumps enable a type of flexibility that can be classified as interruptible load. During a period of interruption, the building draws upon thermal energy stored in the building envelope and recovers the "missing" energy once operation is resumed. This rebounding can be detrimental to the goal of the flex-activation if the device causes an ill-timed spike in consumption when operation is resumed.

InterFlex enabled for the first time in Germany the direct activation of heat pumps by the DSO leveraging the residential smart meter. The focus of use case testing lay primarily on demonstrating the general capability to measure and switch heat pumps via the newly developed technology and investigate the potential pitfalls and teething troubles associated with new technology. Since for the first time the DSO has direct access to metering data on the household level, this also presented an opportunity to better understand customers behaviour and refine concepts for load control.

Figure 15 and Figure 16 display the measured data from two customers between April 16th and 18th 2019. These two serve as an example of how differently heat pumps behave towards the grid. Both customers exhibited a pulsing profile (with implications for the available flexibility to be discussed later), but the pulsing patterns varied widely. The device of Customer #4201491105 in Figure 15 charged for about 1 hour at a time and displays an ability to modulate how much power it was drawing, with the load increasing as the night gets colder. On the contrary, the device of Customer #4205311511 in Figure 16 was charging for about 10 minutes at a time and barely modulated its power demand while charging.

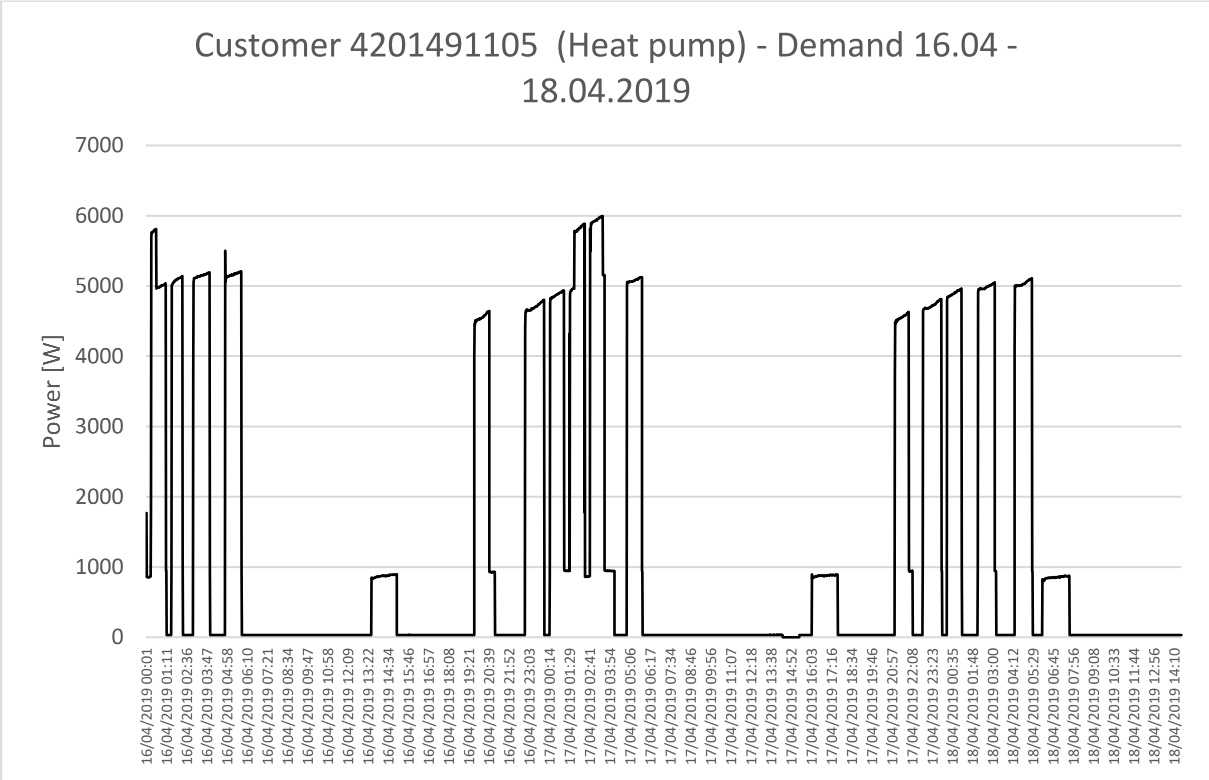

Figure 15 - Power Demand of Heat pump #4201491105 16.04. - 18.04.2019

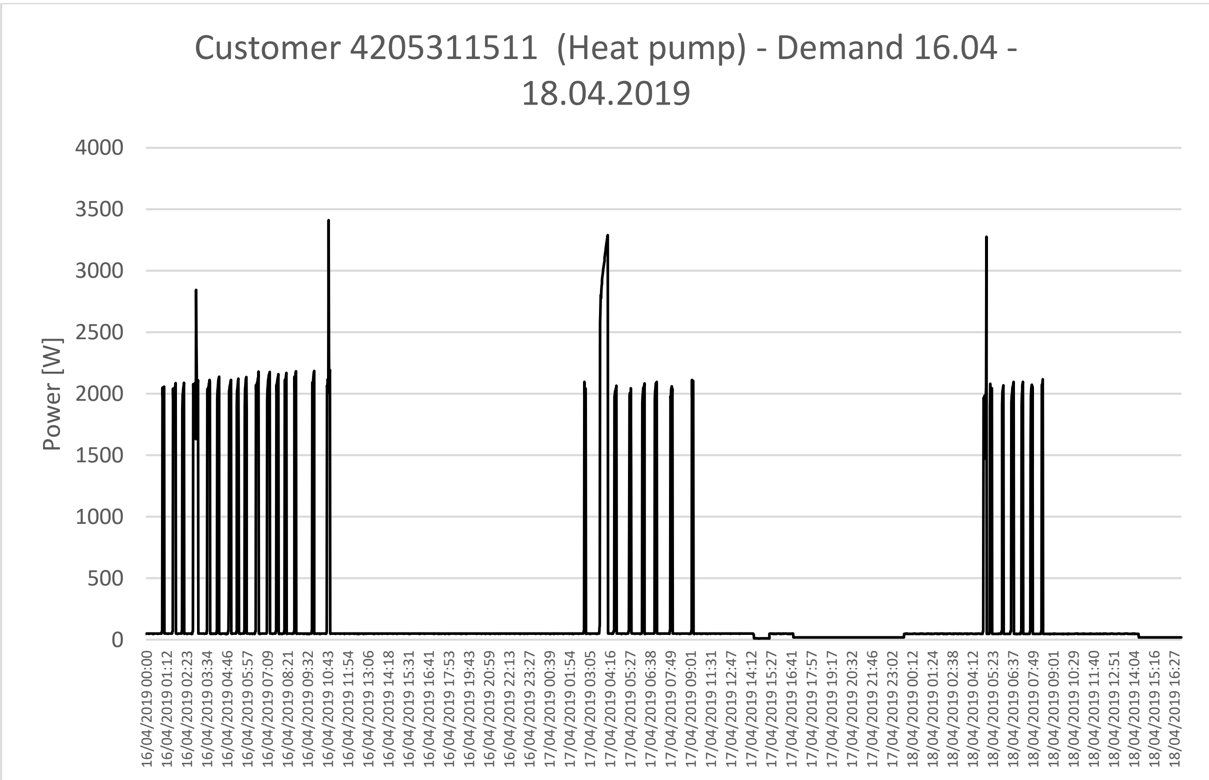

Figure 16 - Power Demand of Heat pump #4205311511 16.04. - 18.04.2019

Both devices responded to test switch signals on April 17th at 2:20 pm, when the Smart Grid hub requested the heater to interrupt operation for 60 minutes. Figure 17 and Figure 18 display the data of the heat pumps for the test switch window between 2:20 pm and 3.20 pm. While both devices did respond to the shut-off signal, there were notable differences in the behaviour of the two. We can see one device reducing power consumption to exactly zero while the second device maintained a base loading of about 11 Watts during shut-down. Furthermore, we see a delay in response in both. The load interruption request was timed for exactly 2:20 pm, #4205311511 reached the floor of reduction of 11 Watts at 2:25 pm with a delay of 5 minutes. #4201491105 reached the target within two minutes at 2:22 pm. The ramp up once the shut-down signal expired exhibits almost the same delays, two and four minutes respectively.

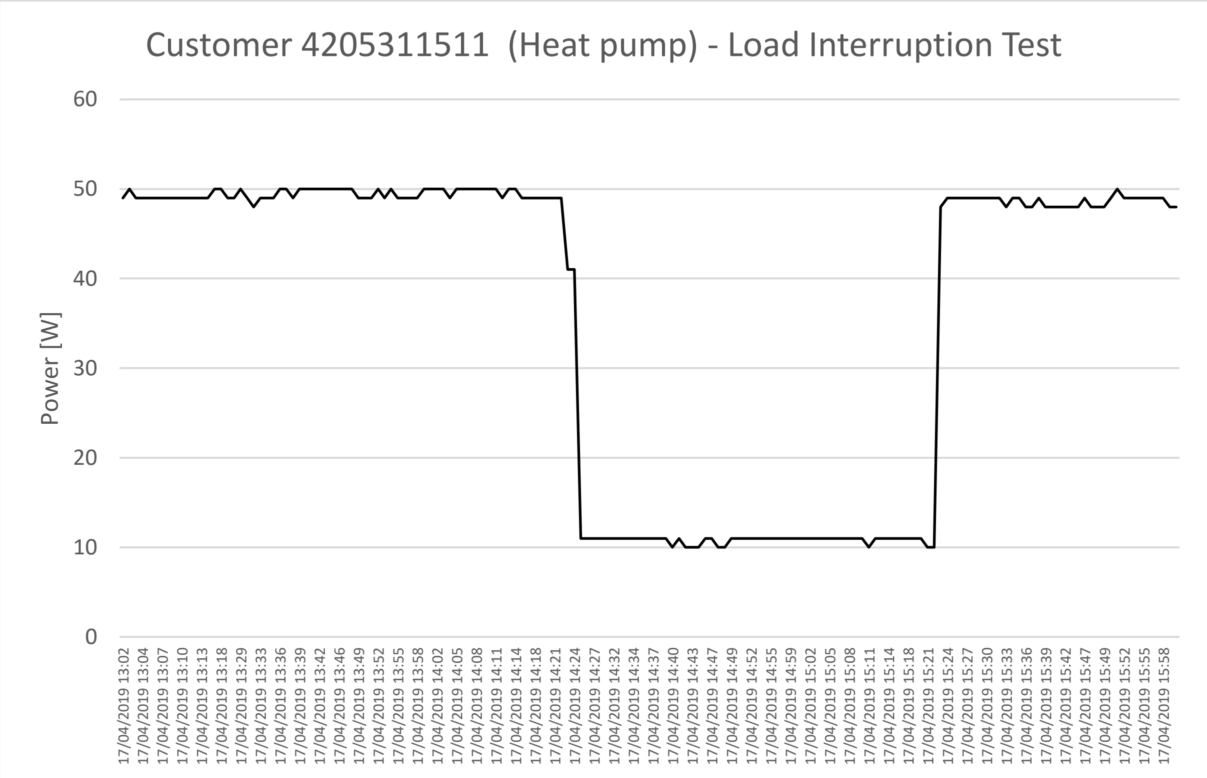

Figure 17 - Load Interruption Test 17.04.2019 at Customer 4205311511

Both switching tests were scheduled for low load scenarios with an expectation of higher ambient temperature on purpose. During the preparation of field-testing customers expressed concerns about their heater being controlled by a third party. Residential heating is of the utmost importance for the comfort and wellbeing of customers and handing a share of control to the DSO made some customers feel uneasy. For the very first field tests with real-life customers, InterFlex therefore scheduled trial switching for hours when an error would not result in immediate loss of noticeable heating power but rather for warm hours that would leave room for fault response.

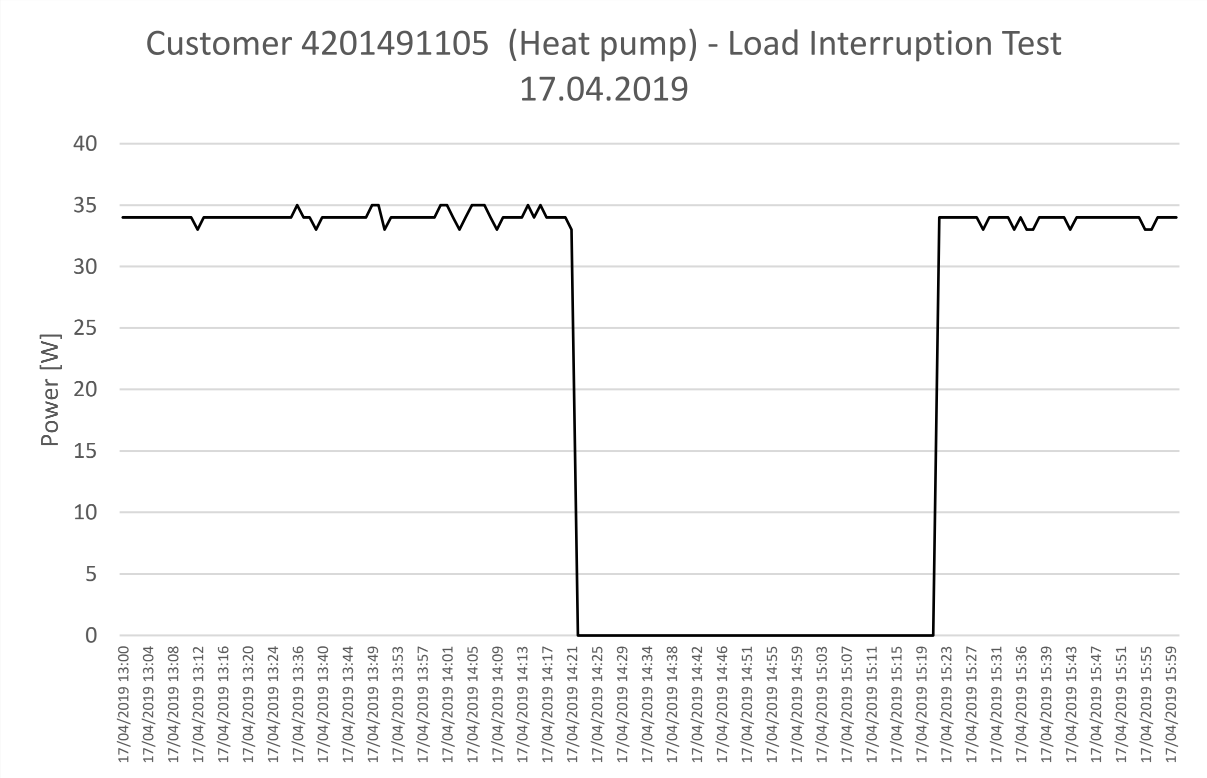

Figure 18 - Load Interruption Test 17.04.2019 at Customer #4201491105

Following up on successful first trials, the next test run was scheduled for times with higher heater load to investigate how devices under load would respond. Figure 19 displays the results for customer #4205321708 during the tests of April 23rd. Load interruption requests were scheduled for 7:00 am and 8:30 am for 60 minutes at a time. The data shows the heat pump reacting precisely as requested, reducing load almost immediately and ramping back up after an hour had passed. Load was reduced to zero Watts, with a delay of 2 minutes (7am shut off and 8am ramp up) and <1 minute (8.30 am shut off and 9.30 am ramp up). The data also shows that the rebound effect of the heat pump catching up on lost consumption did not happen immediately. Instead, the device first went into base load at about 150 Watts before increasing demand to close to peak power at roughly 1200 Watts about 10 minutes later.

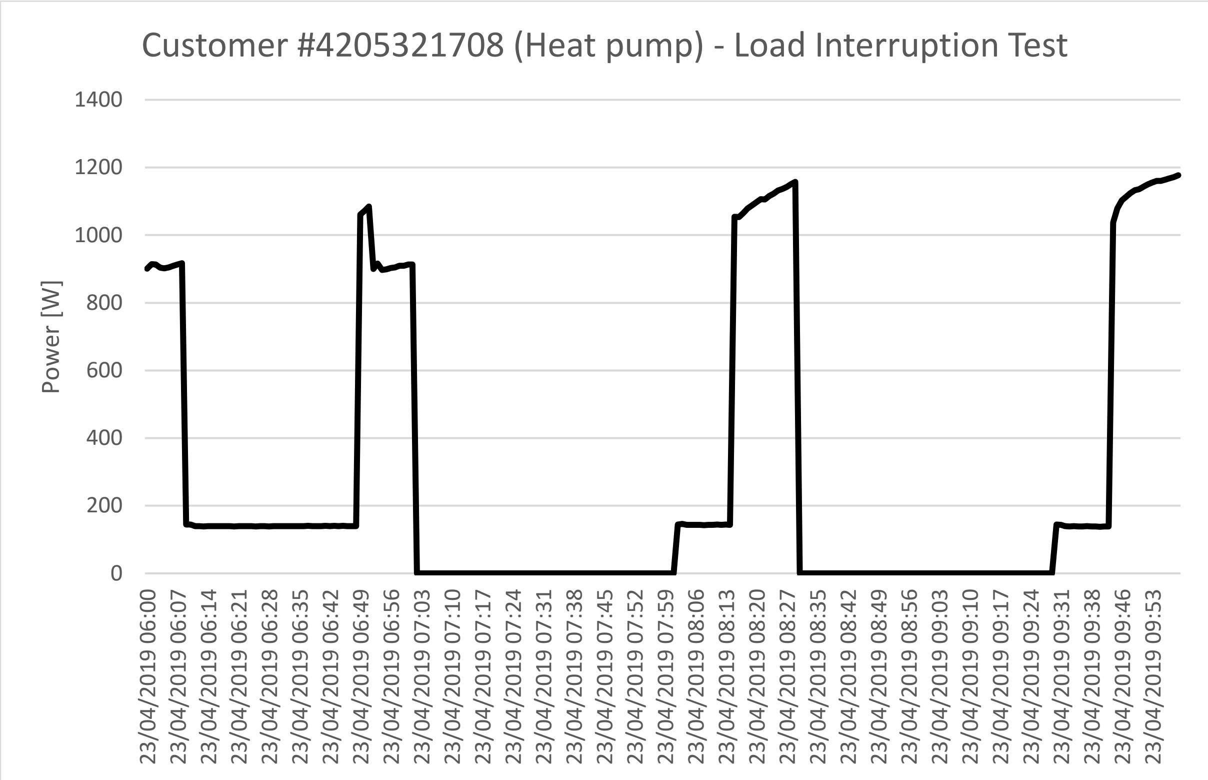

Figure 19 - Load Interruption Test 23.04.2019 of Customer #4205321708

Beside these very successful trials, InterFlex also encountered a fair share of unsuccessful test switching. On 06.05.2019 load interruptions were scheduled for 14 heat pumps at 10 am and 2 pm for 60 minutes at a time. The first test the SGH noted an error in 4 of 14 heat pumps, the second reported errors for 5 of 14.

Figure 20 exhibits the data from customers #4201320273 and #4201488794, both of which were supposed to interrupt their load at 10am and 2pm for 60 minutes at a time. Both failed to respond to the signal. Both can be seen operating during the first shut-down window and neither displays a discernible rebound at the end of the shut-down period. For the second switching window we see #4201488794 ramping down consumption near 2pm. At closer inspection the reduction already starts at 1:52 pm, does settle into a base load of 175 Watts and fails to produce a noticeable ramp up once the control ends. While the data does in fact not show significant load during the switching window it lacks a change of behaviour in any way at or near 2 pm and 3 pm. This suggests that no control signal was received or computed. The maintained standby load of 175 Watts furthers this even more, to the point where the switching at this customer must be considered a failure.

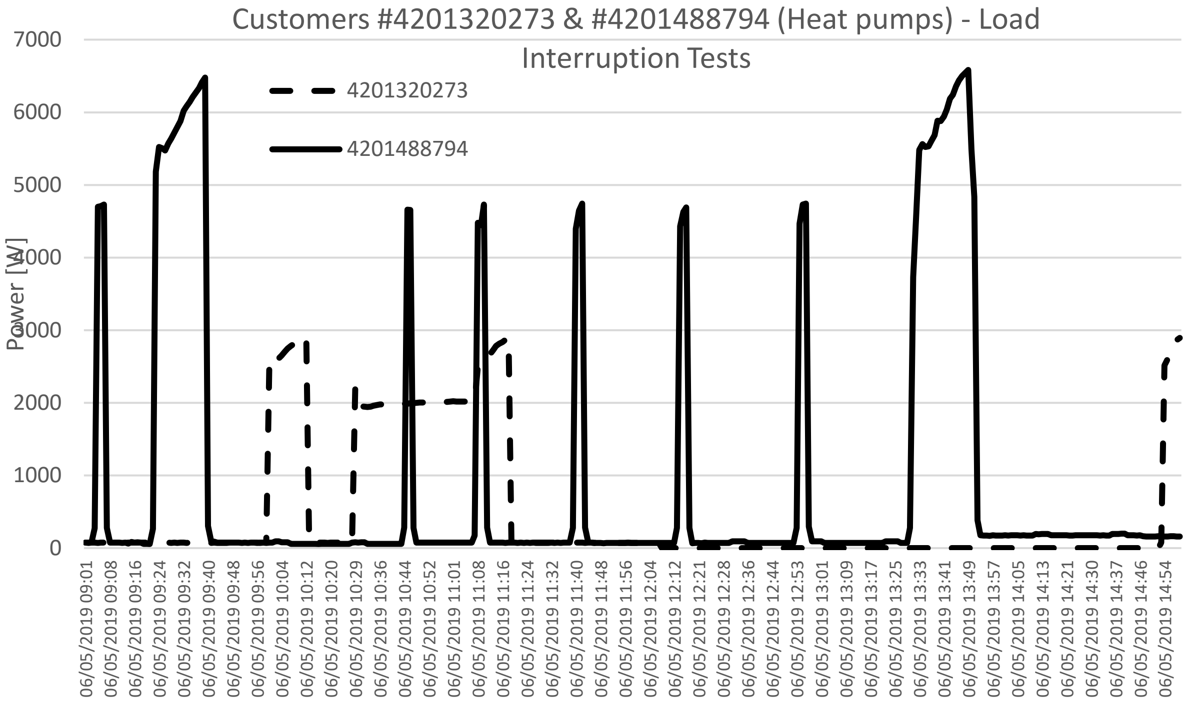

Figure 20 - Load Interruption Test 06.05.2019 of Customer #4201320273 & #4201488794

Figure 21 shows the data at customer #4205321708, a customer who had demonstrated a working connection in previous tests. In this instance however, the customer displays rather odd behaviour. We see a complete shut-down at 11 am and ramp up at 3 pm. Lacking a reliable control confirmation from the customers device we can only guess what exactly caused this behaviour. There are several ways to interpret the data:

1. The customer did not receive any signal and behaved the way he did independently of SGH interaction.
2. The control box failed to sync its internal clock properly the first time around and shut-down was delayed by one hour. Ramp up was not received or ignored the first time around, but then at the second instance at 3 pm.
3. Control signals were sent for shut-down at 11 am and ramp up at 3 pm, but not reported in the SGH's switching protocol.

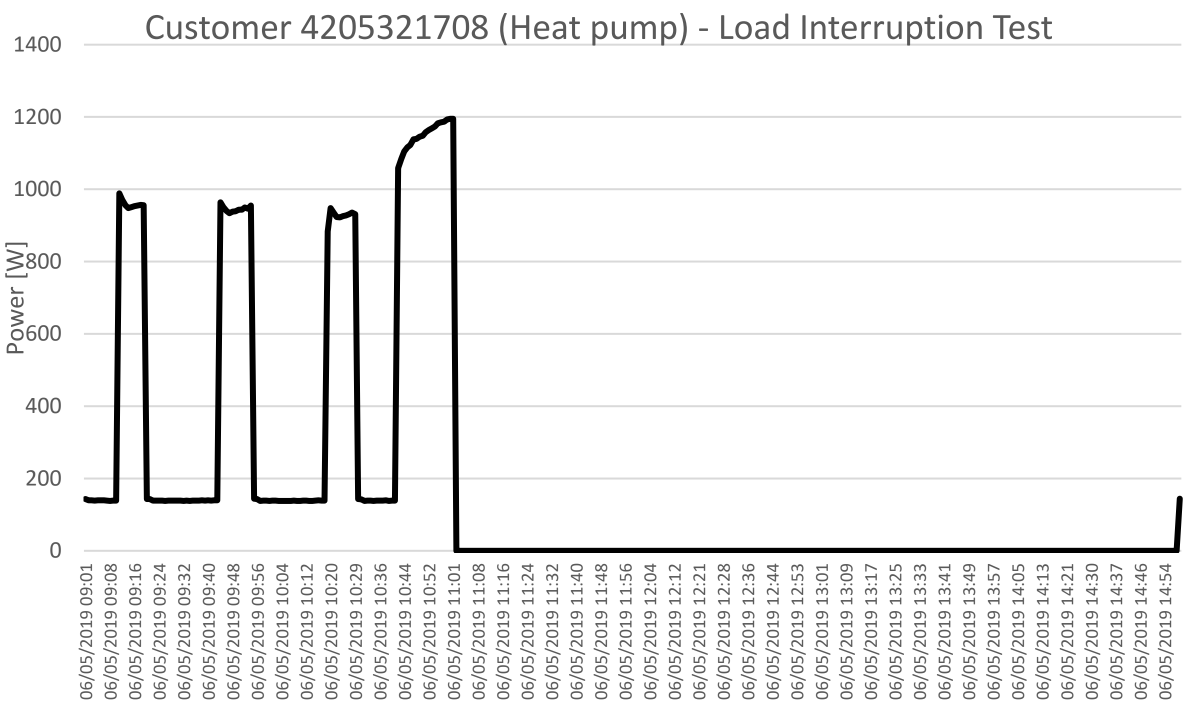

Figure 21 - Load Interruption Test 06.05.2019 of Customer #4205321708

Overall, the rate of success for switching and measuring heat pumps turned out slightly higher than for storage heaters. Not counting individual activation trials and only those fed through the "group-function" of the SGH a total of 131 attempts have been made to switch or measure a heat pump. Of those, 80 activations were reported technically successful, meaning the signal was properly routed through the entire smart meter framework, CLS-channels had been established successfully and data had been transmitted. At a rate of 61% success, heat pumps can be considered a success.

Table 13 - Overview of Heat pump Activations

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	26.03.2019	Live Data Streaming	1	0/1
2	27.03.2019	Live Data Streaming	1	0/1
3	12.04.2019	Live Data Streaming	17	10/17
4	17.04.2019	Load Interruption	14	10/14
5	23.04.2019	Load Interruption	14	10/14
6	23.04.2019	Load Interruption	14	10/14
7	29.04.2019	Load Interruption	14	10/14

8	06.05.2019	Load Interruption	14	10/14
9	06.05.2019	Load Interruption	14	10/14
10	10.05.2019	Live Data Streaming	14	1/14
11	10.05.2019	Load Interruption	14	9/14
Total				80/131

5.7.3. Lessons Learned Use Case 3 – Demand Response

One key learning of InterFlex is that storage heaters come in a much wider variety than expected. Depending on manufacturer, year of installation and policy of the distribution company at the time of installation, storage heater can range in thermal capacity and charging strategy. The most common types are start-loading devices, which simply begin to charge until full once the DSO signal reaches the customer. The second most common are reverse charging devices, which follow a complex logic to delay charging so as to finish charging at the time of anticipated end of the charging slot. Practical experience of InterFlex has shown very clearly, that reverse charging storage heaters require a much more complex control algorithm at best. At worst the way these devices operate could make it impossible to include these in larger flexibility schemes at all. For all intends and purposes of InterFlex, this subset of storage heaters must be excluded from the immediate application of UC3 in practice.

Start-loading devices on the other hand behave exactly as expected and show potential to bring useful flexibility to the DSO. Avacon has a total of 37,000 storage heaters connected to its service area. If we discount half of it as potentially reverse-charging devices, we are left with 18,500 storage heaters, with an average charging power of 5 – 10 kW. If we capture this flexibility using the SGH and SMFW in Germany, this amounts to between 92 - 184 Megawatts of constricted flexibility. Constricted, because the load can only be shifted within a few hours and cannot be activated randomly.

What remains clear is that for the first time, flexibility in storage heaters is now available for productive use by the DSO.

Just like storage heaters, heat pumps have displayed a much wider range of behaviour than initially expected. The load profile of a heat pump appears to be made up of a relatively low base load and spikes or pulses in load when heating is required. Heat pumps differ in their base/peak-ratio, the length and frequency of heating pulses and the range of pulse power. Some run for 60 minutes at a time while others only peak for 10 minutes.

This erratic behaviour makes it difficult to include heat pumps in control strategies that go beyond emergency response actions. If at any given moment a heat pump is off, it might ramp up the next minute and vice versa. And while it seems likely possible to predict the daily consumption of heat pumps in bulk or over greater time intervals, the 1-minute profile appears to be almost unpredictable.

All this puts heat pumps firmly in the class of “interruptible load” with little to no potential for an active use of their flexibility. This can be useful to reduce peak loads in parts of the networks or influence the power exchange with the TSO, it does not offer much hope to support the effort to integrate DER into the network.

Crucially, the heat pump can only be blocked for a certain amount of time, but not be influenced once the blocking period is ending. This means that any rebounding effect happening after a shut-down could potentially undo the intended lowering of global peak consumption in the DSO’s network.

The field trials revolving around UC3 in WP5 have clearly shown the potential and feasibility to replace existing analogue technology with a digital solution that leverages a public smart meter framework. In doing so, new use cases and application become possible and can help to improve DSO operations and support the integration of DER. This is particularly interesting because replacing and upgrading existing technology allows DSO to apply the new technology right away. There is no need for new flexibility mechanisms, only for a new interpretation of existing mechanisms.

The field trials have successfully demonstrated how the SGH makes dormant flexibility available and have shown that direct control of individual heat pumps and storage heaters by DSO grid operation can become a reality.

Figure 22 shows a potential path how use case 3 could be developed into day-to-day operations. Starting with the confirmed but delayed rollout of smart meters in Germany, DSOs could begin replacing the legacy technologies with a SGH + control box infrastructure. Once a sufficient number of elements has been connected nothing stands in the way of migrating the double-tariff mechanism for storage heaters onto the new technology. The next step would be to make active use of the interruption actions for heat pumps. Reducing peak load might not be of the highest concerns for DSOs in Germany today, but it will likely rise in importance in coming years.

The next step would be to include the flexibility offered by heat pumps and storage heaters in the remedial and curtailment action portfolio. The change towards a more comprehensive approach is imminent and these flexibilities could contribute to more efficient congestion management strategies. Finally, depending on the final version of the statutory law governing the application of §14a EnWG, more technologies could be added, such as EV chargers and batteries.

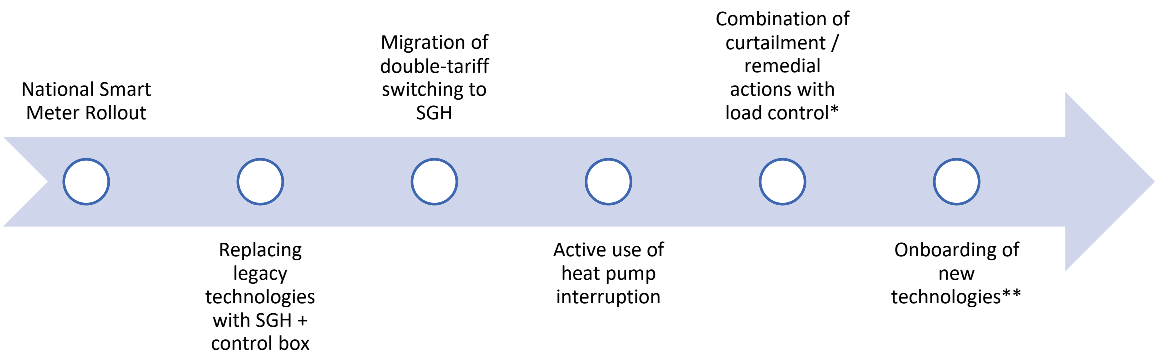

Figure 22 - Potential Path of Development for Use Case 3

The level of technological maturity today is not yet sufficient to put the system into production. Among the shortcomings with the biggest impact are:

1. The lack of LTE coverage in rural areas. Large numbers of customer cannot be onboarded in the first place because of a lack of data communication.
2. Reliability of data transmission. The success rate of switching and measuring remains well below 75%, in the case of real-time data streaming even worse.
3. The SMFW is cumbersome. InterFlex had to put much more effort into bringing the system to life than initially planned for. The reason was a level of complexity and security guidelines beyond anything encountered before.
4. Customer acceptance for the SMFW is low.

Even though this list shows only a part of the remaining shortcomings, the potential upsides described earlier far outweigh these required efforts to bring the system closer to production.

6. COST BENEFIT ANALYSIS

6.1. Use case 1 – Feed In Management / Smart Curtailments

Use Case DE1 was primarily driven by the challenge presented to DSO's in Germany by the renewable energy act. Particularly grid operators in more rural regions are facing difficulties to accommodate all the energy that is produced locally by DER. This energy has a right of way in the grid, but at times the total feed in from distributed and non-dispatchable generators exceeds the local consumption and power export capacity. In critical situations when reverse power flows cause the critical overloading of equipment or violations of local voltage bands, a grid operator can, as a last resort, opt to temporarily curtail the local feed in. The national regulatory agency reports total costs of 373 Mn. € for DER curtailments across Germany in 2016. Over recent years this amount has been increasing and is projected to rise further.

Contrary to a conventional power system with relatively few easily dispatchable power stations, DSO of today must deal with a much higher level of complexity. For example, Avacon connects in total roughly 10 GW of renewable energy generators to its network, which is the equivalent of about 8 conventional power stations. The equivalent of 10 GW in the form of renewable decentralised units however goes into the thousands, 40,000 in the case of Avacon. To control these very large numbers of individual generators requires a new set of control strategies that accounts for complexity and unpredictability.

In many regions of Germany broadcasting control signal across wide areas remains state of the art to handle inevitable curtailment actions. A control signal to reduce or limit power output is being broadcast via long wave radio transmission to a large number of generators, typically clustered to the nearest HV/MV substation. This control strategy was introduced decades ago when a control mechanism for the emerging segment of DER was quickly needed and provided a quick and cost-effective solution. Today however, this technology only allows DSO to choose the lesser evil between two options:

- Include generators in lower voltage levels in the curtailment scheme. The downside of this approach is the lack of individual control signals and accordingly low precision of curtailment actions.
- Do not include generators in lower voltage levels in the curtailment scheme. The downside being a reduced flexibility potential and the discrimination of customer based on their point of connection. It also prevents DSO to effectively use a smart curtailment strategy to accelerate the connection of MV- and LV-connected generators.

Neither option is sustainable in a world with continued growth of DER.

Use case DE1 demonstrated a new approach to the curtailment of distributed generation with a high degree of automation, using state of the art technologies and a future-proof IT-architecture that integrates seamlessly with the national smart meter framework in Germany. It automates the decision-making process to free up the operator capacity for more critical situations and to enable more complex solutions to the curtailment problems.

In turn, more complex and more powerful curtailment algorithms should reduce the total amount of curtailments and reduce the economic costs inflicted by temporal grid congestion, effectively raising the hosting capacity of the distribution network.

Results of field testing in InterFlex have successfully demonstrated the feasibility of individual steering of small scale generators via the smart meter framework. The numbers of pilot customer and volume of their cumulative production did not yield meaningful results in the context of a large DSO like Avacon. To determine the potential benefits and savings enabled by the Smart Grid Hub, WP5 therefore complemented the practical demonstration with theoretical models. The results indicate that by increasing the precision of the curtailment mechanism alone, up to 4% of annual curtailments could be saved.

Annual curtailments in Avacon’s service area amounted to €25,400,000 in 2017 and €43,800,000 in 2018. Assuming that at some point Avacon could apply the concept of the SGH to all qualified generators in its low- and medium voltage networks, a 4% reduction in curtailments would amount to €1,016,000 and €1,752,00 respectively in the reference years of 2017 and 2018. At an average price of 100€/MWh of curtailed energy this also translates to an additional 254 and 438 MWh of additional renewable energy integrated into the system.

6.2. Use Case 3 – Demand Response

The case for Demand Response in Germany is a difficult one. The current regulatory framework does not enable dynamic pricing for end customers yet and hence a true flexibility market for flexible load installations in the residential segment does not exist.

Regulation does however enable a few particular use cases that enable the DSO to leverage flexibility to support and optimize the operation of its networks. One such use case has been designed on the basis of InterFlex Use Case DE3.

In the German energy market, customers with an annual demand of 100.000 kWh or less are being treated as standard load profile customer. DSO defines a standard load profile for these customers, based on the assumption that at the relevant level of aggregation the behaviour of these customers can reliably be forecasted based on the day of the week, season and ambient temperature. The standard load profile is assumed to be the same for all customers within a certain segment in any given grid service area[5].

[5] At the time of writing this report it is not entirely clear, whether or not customers remain in the reference profile segment once they are equipped with a smart meter. Relevant articles in metering law and guidelines by the national regulator hint that controllable loads must under any circumstance be managed based on their actual load curve once they receive a smart meter, which would put the presented business view of UC DE3 at jeopardy.

As balancing responsible party for the pool of their customers, suppliers have to ensure delivery of the applied standard load profile for their customers in each of their balancing circle. In reality, the actual demand of residential customers and small businesses does oftentimes deviate from the predefined standard load profile. Contrary to larger customers, the responsibility for these deviations lies with the DSO. In practice, each DSO forecasts the deviation of actual behaviour from the standard load profile daily. During the day, DSOs balance these deviations with transactions on the intraday spot market.

The ¼-hourly intraday auctions are settled on short notice and tend to display a high variance in prices. A small shift in trading schedules could potentially make a big difference to the cost of balancing.

With InterFlex, Avacon is now able to influence the behaviour of flexible loads. Residential storage heater and heat pumps which participate in the interruptible load mechanism receive a discount on their grid charge in return for offering flexibility to the DSO. Currently, these control signals are carried out via a broadcast signal that does not allow for dynamic or individual steering. InterFlex enables individual control, dynamic steering and makes the customers behaviour fully transparent. With this, a smart flex-control mechanism can be deployed that takes advantage of the offered flexibility to reduce the costs for balancing.

In its current iteration, the system[6] forecasts the individual load of each customer and the power price for the next day. Heating schedules are then optimized for minimal balancing costs, meaning that the charging periods for storage heaters can be delayed to avoid the most expensive ¼-hour slots of the following day.

By shifting load away from the most expensive times and towards cheaper hours, this mechanism can save costs compared to the baseline of existing operations. Simulations have shown that in the best case, up to 60€ per year per customer could be saved.

The immediate potential is limited to customers with a certain type of heater. Depending on the speed of the smart meter roll out and rate of decline of the number of storage heater installation, a total of 10,000 to 15,000 installations can be reached within the next 5 - 10 years.

If we include a different type of heaters, so called reverse charging units, the specific savings drop to 25€ per customer per year.

[6] The IT solution to handle the forecasting and optimization of loads had not been funded by InterFlex, the use case however ties directly into the work and results of InterFlex. Essentially the results of InterFlex enabled this advanced use case.

The inclusion of heat pumps would raise the market volume even further, as we can expect 10,000 to 15,000 of these installations at Avacon. The savings per customer are more difficult to determine, but we can assume savings of 20€ per customer per year.

6.3. Summing up the financial benefits

Use case 1 and 3 complement each other in terms of financial impact, as one covers generators and the other flexible loads. Both use cases target improvements in DSO operations by reducing costs for balancing and curtailments. Neither does generate additional revenue streams in competitive markets, so both use cases reduce DSO operational costs and ultimately help lowering grid charges for end customer.

Use cases have been designed to scale seamlessly along with the rollout of smart meter and control boxes in Germany. The main driver for the benefits is hence the speed of the rollout. Officially, the rollout is yet to begin and an exact date is unknown. For the sake of this analysis, we assume a start of the smart meter rollout at the beginning of 2020. Taking into account that the mandatory status of the control is still being discussed we further assume the roll out for devices with control box to ramp up slower.

6.3.1. Financial Benefits Use Case 1

The current estimate for the monetary benefit of use case 1 applies to the total sum of curtailments across Avacon entire service area. It is also limited by the installation of smart meters and control boxes. For the sake of this CBA we assume that Avacon can begin to equip DER with control boxes beginning in 2020. There are about 13,000 customers who are potential candidates to participate in use case 1 once the rollout is underway. We assume a slow ramp up and then a linear growth to cover the entire market in 2030. The growth path is shown in Table 14.

Table 14 - Forecasted Number of DER Equipped with Smart Meter and Control Box

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
PV w/ Control Box	200	1000	2511	3822	5133	6444	7755	9066	10377	11688	13000
In % of total population	2	9	19	29	39	50	60	70	80	90	100

The other determining factor for the benefits of use case 1 is the expected annual curtailments carried out by the DSO. Lacking a reliable estimate for future years we assume that annual curtailments remain stable at the 2018 level and decline by 10% per year beginning in 2026.

Table 15 - Forecasted Annual Curtailments

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Annual Curtailments in Mn €	43.8	43.8	43.8	43.8	43.8	43.8	39.4	35.5	31.9	28.8	25.8
Change to previous year	0	0	0	0	0	0	-10%	-10%	-10%	-10%	-10%

Naturally, the full potential of savings can only be captured once the system is scaled across the entire population. Until then, the savings must be reduced according to the share of the general population that is participating in use case 1 in any given year. In this case, we assume the total benefit to be a reduction in curtailments by 4%. The savings in any year before we reach full potential can be estimated by taking the share of equipped customers into account.

Table 16 - Annual Savings Expected from Use Case 1

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Annual Curtailments in mn €	43.8	43.8	43.8	43.8	43.8	43.8	39.4	35.5	31.9	28.8	25.8
Maximum potential in Mn €	1.75	1.75	1.75	1.75	1.75	1.75	1.57	1.42	1.28	1.15	1.03
% equipped customers	2	9	19	29	39	50	60	70	80	90	100
Savings in k€	**35**	**158**	**333**	**508**	**683**	**876**	**946**	**993**	**1021**	**1034**	**1034**

6.3.2. Financial Benefits Use Case 3

For the residential heating segment, we assume a slightly slower ramp up and that the full potential will be reached in 2030. The forecast of customers equipped with a control box and smart meter assumes an even distribution between standard- and reverse charging storage heaters (SH SC and SH RC) and an annual decline of the number of storage heaters of 4%.

Table 17 - Expected Numbers of Controllable Elements in Avacon Network

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SH SC	69	69	69	2366	3364	5082	6415	8627	10219	10441	10663
SH RC		69	69	2366	3364	5082	6415	8627	10219	10441	10663
HP	134	137	137	3179	4520	6829	8619	11592	12570	13061	13570

Applying the estimated savings per customers per year of 60€ per standard charging storage heater, 25€ per reverse charging storage heater and 20€ per heat pump gives us the expected annual savings delivered by applying use case 3 in practice.

Table 18 - Expected Annual Savings Generated by UC DE3, values in € per year

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SH SC	4140	4140	4140	141960	201840	304920	384900	517620	613140	626460	639780
SH RC	-	1725	1725	59150	84100	127050	160375	215675	255475	261025	266575
HP	2680	2740	2740	63580	90400	136580	172380	231840	251400	261220	271400
Total	**6820**	**8605**	**8640**	**264690**	**376340**	**568550**	**717655**	**965135**	**1120015**	**1148705**	**1177755**

6.4. Costs to develop and operate the system

Development and deployment of the Smart Grid Hub have been funded as part of the InterFlex field trial in work package 5. Development costs for the SGH platform and the associated efforts to integrate the SGH with grid operations and the public smart meter infrastructure amounted to roughly 2.2 Mn €.

Table 19 and Table 20 show the breakdown of costs in investment and operations for the SGH. It is important to note that this CBA does not include the costs for smart meter and control box. While these are crucial for the deployment of the concept, these devices will be installed by the metering service provider along with the mandatory rollout of smart meters in Germany. In this sense, the application of the Smart Grid Hub builds upon the availability of these devices but is not considered the trigger for the incurrence of these costs. This CBA also strictly considers only costs associated with the development and deployment of the Smart Grid Hub, all costs and efforts associated with the execution of field tests and costs incurred by internal personnel of Avacon is not being reflected.

Table 19 - Investments Directly Associated with the Development of Smart Grid Hub

Smart Grid Hub Investments		
Smart Grid Hub Development & Deployment		1,759,244 €
Modifications of Smart Meter Administration Service		341,500 €
Modification of Smart Meter Gateway Firmware		34,375 €
Smart Grid Hub Hardware		93,815 €
	Total	**2,194,559 €**

Table 20 - Costs for Operation of Smart Grid Hub

Smart Grid Hub Operations (per annum)		
Licensing		65,000 €
Operation and maintenance software		77,000 €
Operation and maintenance of hardware		100,000 €
	Total	**242,000 €**

6.4.1. Business Case – Financial View

For the overall financial view, we assume the annual costs for operation and maintenance to remain stable. We further assume the costs associated with the design, development and deployment of the Smart Grid Hub to be incurred and depreciated all at once in period 1. We further assume a discount factor of 6%.

Table 21 - Business Case WP5

k€	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
SGH Invest	-2195		4140	4140	141960	201840	304920	384900	517620	613140	626460	639780
SGH O&M	-242	-242	-242	-242	-242	-242	-242	-242	-242	-242	-242	-242
Savings UC1		35	158	333	508	683	876	946	993	1021	1034	1034
Savings UC3		6.8	8.6	8.6	265	376	569	718	965	1120	1149	1178
Annual Cash Flow	-2437	-200	-75	100	531	817	1203	1422	1716	1899	1941	1970
Discounted Cash Flow	-2437	-189	-67	84	421	611	848	946	1077	1124	1084	1038

From a purely financial perspective, taking into account all results obtained in the InterFlex field trial and the assumption outlined above, we believe that the Smart Grid Hub promises a return on investment within 3 years and at full capacity savings of up to 2 Mn € per year.

7. KPI EVALUATION

The Grant Agreement states that the field trials of work package 5 shall be evaluated on the basis of a number of key performance indicators. As mentioned already, the scope of the demo in Germany had to be adjusted slightly to account for the delay in the operation of the smart meter framework in Germany. At the time of submission of the GA it was reasonable to expect the smart meter framework in Germany to be fully operational, in reality it wasn't and InterFlex had to build many of the required capabilities and interface first in order to enable use cases testing. As a result not all KPI stated in the Grant Agreement could be evaluated, the field trials did however deliver data on a subset of KPI that serves to evaluate the technology.

The initial list of KPI is given in Table 22.

Table 22 - List of KPI according to the Grant Agreement

KPI #	Key Performance Indicator	Description	Covered in Use Case	Unit
1	Speed of data transmission	- No. of established connection per time unit - Transmitted data volume per time unit	DE1-2-3	1/s
2	Security of data transmission	- Number of connection losses	DE1-2-3	1
3	Reliability of data transmission	- Number of connection losses	DE1-2-3	1
4	Observance of grid restrictions	- Relevant grid parameters kept within limits	DE1-2-3	1
5	Anticipation of violations of grid constraints and good choice of measures to avoid these	- Correct forecast* - Avoidance with least number of interventions	DE1-2-3	1
6	Amount of curtailed energy	- Amount of curtailed energy compared to 7theoretical optimum (least intervention)	DE1-2-3	kWh
7	Speed of command execution	- Number of executed commands per time unit	DE1-2-3	1/s

8	Overall costs	- Comparisons of conventional grid expansion measures with flex activation	DE1-2-3	€
9	Active participation of all kinds of flexibility	- Each type of technology should be represented in the test system and have the possibility to act as flexibility	DE1-2-3	1
10	Precision obtained by SGH for execution of control center commands	- Deviations of resulting figures obtained by SGH from the original high level target figures	DE1-2-3	kWh
11	Number of interventions	- Number of interventions at optimal level	DE1-2-3	1, kWh

Of these, KPI 1,2,3, 7 and 8 could realistically be determined with data obtained in the field tests. Other KPI were designed under the assumption that more complex use case algorithms would be implemented, which for a variety of reasons that lay outside of the responsibility of InterFlex, was not feasible.

7.1. KPI 1 Speed of data transmission

KPI 1 was designed to measure the performance of the data transmission uplink and command signal downlink. During implementation and field testing, it became clear that the smart meter framework would not allow for full transparency of bandwidth and data volume. The way the communication up- and downlink are designed by the regulatory guidelines prevents any participant from having complete transparency over the entire command and data chain; instead, the information is fragmented among the different agents of the process. Avacon as operator of the Smart Grid Hub and the required head end system to connect to the smart meter backbone could only see so far. Hence the measurements for KPI 1 are limited to the number of connections established per time unit while the transmitted data volume could not the determined with acceptable precision. What can be said is that data bandwidth was always sufficient for carrying out the use case field testing and never imposed limitations on the amount of data available or number of control signals to be communicated.

The field tests showed that the number of established connections largely depended on the status of the secure communication channel to the customer. When a CLS-channel was already active, the system would perform well and establish a connection in less than 60 seconds or 1 per minute. If the channel had to established first, performance dropped to 0.3 – 0.5 connections per minute.

7.2. KPI 2 Security of data transmission & KPI 3 Reliability of data transmission

KPI 2 and 3 were designed to evaluate the reliability of the communication link. Particularly in the context of distribution grid operation it is imperative that a communication link is stable and reliable. Flexibility which isn't available could not be accounted for in the planning and operation of the network.

To get a handle on the performance of KPI 2 and 3, work package 5 recorded the number of successful switching and metering requests. Table 23 shows the results for UC1. At a failure rate of 28% the system appeared to be performing acceptably for a pilot system, but clearly was not yet ready for live operation in the context of day to day grid management.

Table 23 - KPI 2 for UC1 field testing

Test #	Trial #	No. of connection losses	Failure rate
1	1	2	66%
	2	2	66%
	3	3	100%
	4	1	33%
2	1	8	42%
3	1	1	6%
	2	1	6%
	3	2	12%
	4	4	25%
5	1	0	0%
6	1	6	46%
Total		30	28%

Table 24 and Table 25 show the evaluation for use case 3 for storage heaters and heat pumps. The rate of failure here amounts to 51% for storage heaters and 39% for heat pumps.

Table 24 - KPI 2 for UC3 (Storage Heaters)

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	14.04.2019	Modification of Charging Slot (Delay Start 2hr)	3	2/3
2	15.04.2019	Modification of Charging Slot Delay End 2hr)	3	2/3
3	15.04.2019	Modification of Charging Slot (Delay 1hrs)	3	2/3
4	22.04.2019	Modification of Charging Slot (Delay 0.5 hrs)	4	2/4
5	24.04.2019	Load Reduction	4	2/4
6	26.04.2019	Live Data Streaming	4	0/4
7	29.04.2019	Load Reduction	4	2/4
8	29.04.2019	Load Reduction	4	2/4
9	29.04.2019	Load Reduction	4	2/4
Total				**16/33**

Table 25 - KPI 2 for UC3 (Heat pumps)

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	26.03.2019	Live Data Streaming	1	0/1
2	27.03.2019	Live Data Streaming	1	0/1
3	12.04.2019	Live Data Streaming	17	10/17
4	17.04.2019	Load Interruption	14	10/14
5	23.04.2019	Load Interruption	14	10/14
6	23.04.2019	Load Interruption	14	10/14
7	29.04.2019	Load Interruption	14	10/14
8	06.05.2019	Load Interruption	14	10/14
9	06.05.2019	Load Interruption	14	10/14
10	10.05.2019	Live Data Streaming	14	1/14
11	10.05.2019	Load Interruption	14	9/14
Total				80/131

Table 26 - General Technical KPI reported on Consortium Level

CALCULATION DETAILS			
KPI	Baseline	SG	Comment
Flexibility	0 (Without Smart Grid Hub there is no flexibility available for DSO)	+177,3 kW (PV) -72 kW (Heating)	Results show that >95% of 15-min intervals less than 5% of flexibility is available as bi-directional flexibility
Hosting Capacity	Annual curtailments without smart grid hub	Reduction in curtailments of up to 4%	Field tests demonstrated technical feasibility, potential confirmed with simulations
Customer recruitment	200 (Ambition)	360 (expressed interest)	60 could be integrated technically. Remaining customers could be integrated due to lack of mobile network coverage, lack of space for meter equipment installation or incompatible controllable device.
Active Participation	5 (Ambition)	3	EV chargers and batteries could not be integrated
Cost Savings	0	Results of simulation	Assumption complete rollout of smart meters and integration of all compatible devices.

KPI RESULTS						
Flexibility	2	0	5% * (+177,3 kW // -72 kW)	5%	>0	Total available flex is only considered what is connected to SGH, KPI reflects what can reliably be used as bi-directional flexibility in typical scenario
Hosting Capacity	1	-438 MWh/a	-420,5 MWh/a	4%	>0	Hosting capacity measured as reduction in annual curtailments
Customer recruitment	1 2 3	20 40 20	27 52 25	135% 130% 125%	100%	KPI only considers flawless installations
Active Participation	1 2 3	5 5 5	3 3 3	60% 60% 60%	100%	EV chargers and batteries could not be integrated
Cost Savings	1 3	43,800,000€ Confidential	42,480,000€ 1,177,755€	3% 1,177,755€	10%	Best case scenario max potential savings if applied across entire service area of Avacon

Table 26 reiterates the technical KPI on consortium level as reported in Deliverable 2.5. Work package 5 reported on 5 global KPI.

7.2.1. Flexibility

This KPI was designed to measure the success of demos in activating flexibility. The baseline in this case was 0 because without the technology developed in InterFlex the DSO did not have the tools required to utilize LV-connected flexibility. As result, InterFlex increased the available flexibility in the field test region by +177 kW and -72 kW nameplate rated power of the connected devices. If this flexibility was locally confined to one or two secondary substations this would be a respectable amount of flexibility to support the operation of individual LV-networks.

The flexibility was however distributed across a wider geographical area which made its imperceptibly small as seen from the higher level networks. The analysis done as part of use case DE2 further highlighted that only a small percentage of the rated power of flexible devices can be counted on as part of a bi-directional flexibility scheme. The ambition level of >0 was met.

7.2.2. Hosting Capacity

Given that DER curtailments are sadly daily business for DSOs in Germany, this KPI was of utmost importance for WP5. Because of the geographical distribution of participants however, the field test did not show a measurable impact on actual curtailments. Instead, InterFlex modelled a wide-spread application of the use case and ran simulations to estimate the potential impact. The results hinted at a potential reduction in curtailments of up to 4% of annual curtailments. As a baseline we took the total annual curtailments of 438 MWh and applied the potential reduction of 4% to arrive at 420 MWh of remaining curtailments and an increase in hosting capacity of 18 MWh per year. The ambition level of >0 was met.

7.2.3. Customer recruitment

The German demonstrator relied heavily on the participation of end customers. The initial goal was to contract enough participants in each technology bucket to achieve meaningful results. A minimal ambition was defined as 20 customer each for UC1 and UC3 and 40 for UC2. Ultimately the minimal ambition was outperformed. However the global ambition to sign 200 participants could not be met due to technical complications with customer installations and a lack of mobile network coverage.

7.2.4. Active participation

KPI “Active Participation” was devised to measure the diversity of a demo’s flexibility portfolio and represents the number of different technologies that were part of the field test demonstrations. The initial ambition was to reach 5 technologies (PV, heat pump, storage heater, EV, ESS) of which eventually 3 could be connected (PV, storage heater, heat pump). EV and ESS were among the pool of potential participants, but regulatory barriers and technological challenges hindered the integration in field tests. The ambition level of 100% was not met.

7.2.5. Cost Savings

The basis for the cost savings KPI is discussed in detail in chapter 6 – Cost Benefit Analysis. If we interpret the potential reduction in reimbursement obligations originating in DER curtailment then almost 1.2 Mn € could be saved. This represents savings of c. 3%, well below the ambition level of 10%.

8. RECOMMENDATIONS FOR THE REGULATOR

InterFlex was able to demonstrate 3 use cases that represent flexibility activation by the DSO that are covered under the current national regulatory framework in Germany. The temporary curtailment of DER, the temporary interruption of heat pumps and the control of storage heater installation that fall under the double-tariff mechanism. And even though these mechanisms were not devised as parts of a DSO-based flexibility concept, they can be interpreted in such a way. With these tools in place, Germany has taken the first step towards an understanding of flexibility in power networks that can support the ambitious goals for our energy transition. Still, we find that there is room for improvement.

8.1. Barriers in national regulation to increase the use of batteries

For system operators a battery presents an ideal source of flexibility. Batteries can deliver bi-directional flexibility and do so independently of daytime, weather or season. This makes batteries particularly useful and sources of flexibility of the second highest grade. The only real downside is their limitation in duration when providing flexibility. Depending on the technology and capacity, a battery runs out of flexibility within a few hours.

Germany has seen a tremendous growth in domestic battery systems, almost exclusively in combination with a rooftop PV installation. By late 2018, the number of domestic battery installations exceeded 100,000 units. The majority of these systems range from 5 to 10 kWh in useable storage capacity and charging / discharging power between 2 and 6 kW. Assuming a fair mix of available systems an average customer might offer ±4 kW and 7.5 kWh of capacity. Across the entirety of all installations, the theoretical flexibility potential adds up to 400 MW and 750,000 MWh.

This flexibility potential remains very difficult to capture. The feed in by rooftop PV has posed a significant challenge for DSOs in Germany. Nowadays the cumulative feedback of PV in a given low voltage network often exceeds the peak load for which network and distribution station were designed. DSOs operating in rural and suburban areas are highly affected by the growth of rooftop PV and have therefore no other choice, but to replace and uprate existing transformers. The peak feedback also causes voltage to rise along the feeder. This PV-induced voltage rise frequently pushes the local voltage to or beyond limits, requiring the DSO to add more feeders and reinforce existing networks. In some areas, these effects can be countered to some degree with the deployment of voltage regulating distribution transformers and proactive reactive power management. But the cumulative feedback of PV in rural networks remains a big challenge for DSOs.

From an economic point of view, the situation isn't ideal either. DSOs in Germany are subject to a regime of incentive regulation. The regulator grants an annual total revenue for the DSO, which is then recovered via grid charges that apply on energy consumption. For household customers, grid charges apply per kWh of demand. Customers who decrease their demand from the public grid consequently contribute less to the financing of the network, which is in and by itself considered a fair effect. Taken to the extreme however we find a situation, where the wealthy areas withdraw from refinancing the public grid by substituting grid-demand with self-generated PV power, leaving urban areas and less wealthy neighbourhoods to cover the cost of the network.

All these effects led the government and regulator to encourage battery systems in combination with a PV generator as means to increase self-consumption and reduce feedback to the public network. The rationale was that by increasing self-consumption and reducing grid interaction, the overall costs of integrating DER into low voltage networks could be kept in check. While it can be argued that this aim has been achieved to some extent, the regulations applying to batteries have created tall barriers to use domestic batteries for anything but the increase of self-consumption.

In Germany, renewable tax applies to self-consumption just like any other consumption. That means if a customer is producing his or her own electricity, a renewable tax of currently 6,405 cent/kWh applies. Installations with a rated power of less than 10 kWp are exempt from this rule. This exemption does extend to batteries, if they are considered "EE-Stromspeicher" or "Renewable Power Storage". To qualify as such the owner must ensure that the battery can only be charged directly from the PV and under no circumstance from the public grid.

Figure 23 depicts the different power flows in an exemplary household with PV and a battery. A widely accepted solution to ensure the status of renewable storage is to install a power flow indicator at the customer's point of connection and feed the information to the battery inverter. The inverter then monitors the household's net exchange with the grid and stops charging whenever the house is drawing energy from the outside.

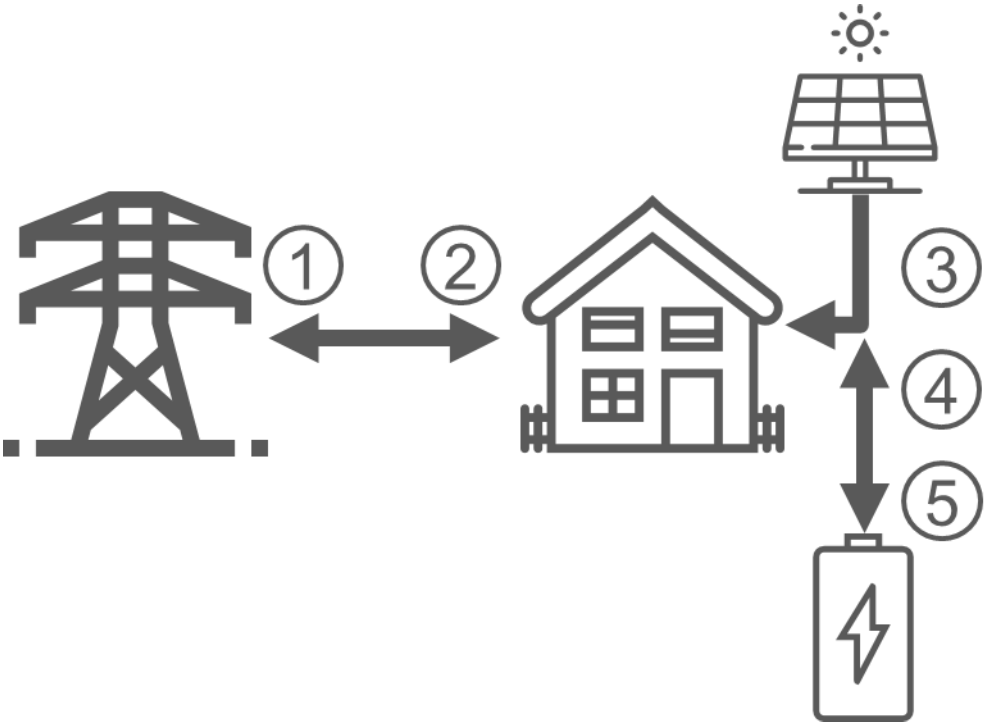

Figure 23 - Depiction of power flows in households with PV + battery installation

Installations like these are commonplace in Germany and represent all storage offers among the acquired InterFlex field test pilot customers in Germany. Because of this, these customers could not be integrated in the InterFlex field trial, even though they were willing and open to participating in the project. Including these customers in the field trials would have required disabling of the power flow indicator and an alteration of the mode of operation of the battery system. While this could have been technically possible, it defeated the purpose of InterFlex Germany, namely to activate dormant flexibility without interfering with local installations. In addition to this, the customer would also suffer from the application of the renewable tax on the share of self-consumption that was stored in the battery prior to consumption. A simple example of a customer with 5 kWp installed capacity would produce about 5,000 kWh of solar power in Germany. A typical battery system might increase the self-consumption by about 1,500 kWh per year on which the renewable tax would apply. At 6.5 cent/kWh that would be 97.5 € per year of additional cost for the household. Keeping in mind that under the current market design there is little to no chance to counter these effects with market-generated income for the flexibility, altering the battery installation did not appear to be a reasonable choice.

The way in which the renewable tax is applied under these circumstances has created a situation where customers are clearly discouraged from designing a storage-PV-installation that could also offer flexibility to the DSO.

In 2017 an updated renewable energy act introduced additional rules that should, in theory, alleviate this issue. Now, storage systems could be used for multiple use cases. A requirement for this is that customers install several metering points to ensure that power flows could be clearly discriminated on a 15-minute basis. In order to qualify for the renewable tax exemption but still be able to participate in other flexibility markets customers would have to have their main point of connection, their PV-production and their battery metered in 15-minute intervals with a certified meter. They would also be required to discriminate between battery-stored self-consumption and exchange between battery and grid on a 15-minute basis and report this data to the DSO for the handling of the renewable tax.

While this rule poses an improvement over the previous situation by introducing the possibility of multiple-use batteries in households, it is still too complicated. For one, it requires setting up the system for this purpose from the start, as the space for additional metering equipment is oftentimes difficult to find later after installation. The lack of space for metering equipment is oftentimes also the reason why retrofitting older systems according to the new regulation doesn't make much sense. Secondly, it also introduces additional costs.

In InterFlex Germany, all potential participants were set up according to the old rule and did not have the metering equipment required to participate as mixed-use storage systems.

A lack of commercial offers and use cases for flexibility in-front-of-the-meter has led customers to put emphasis solely on maximizing individual self-consumption. This shows in the way regulation deals with residential batteries but also in the dimensioning of storage systems for private use.

8.2. Barriers to utilize flexibility by interruptible loads and electric vehicles in particular

The control of flexible elements in low voltage networks by the DSO is governed in §14a Energy Industry Act and states that DSO must offer a discount on grid charges to those customers and suppliers, that are offering some form of controllability in return. It explicitly states that electric vehicles fall under this definition. It does not comment on the exact meaning of "controllability" or the design of the contractual agreement between DSO and owners of interruptible loads, neither does it make comments on how the discount is be determined. Instead, it empowers the government, in this case the federal ministry of economics, to define these details in a statutory law that defines which control actions shall be owned by the DSO and which ones belong to the supplier. It shall also take care of adjusting the laws governing the meter service provision to enable these use cases.

This mandate has been introduced 2016 and since then no progress has been made. Rather discouragingly, the German government has just announced that the first draft of the statutory law in question will be delayed at least for another year until 2020. Taking into account that the draft will require political discussions and go through the legislation process we can expect results not before 2021.

This situation is dissatisfying for many stakeholders in the field of local flexibility. DSOs, customers, aggregators, suppliers and operators of DER alike share the opinion that this situation hinders the energy transition in Germany. The lack of a clear regulatory framework and a lack of vision makes it increasingly difficult to justify the efforts towards developing much needed technologies and strategies for the management of flexibilities in low voltage networks. InterFlex has demonstrated a few use cases that could be implemented under certain interpretations of the current regulatory framework. These use cases, as many others, are at risk if the expected law overturns today's expectations.

Another roadblock in this regard is the complete lack of a framework on how domestic energy storage systems (ESS), electric vehicles (EV) and chargers (EVC) fit into the picture. The established technologies in domestic heating and small-scale generation can provide some flexibility under existing guidelines. For ESS, EV and EVC however there are no rules in place and accordingly no way to begin testing and developing flexibility mechanisms. As far as InterFlex is concerned, this situation made it impossible to include ESS and EV(C) in the real life field tests.

8.3. Recommendations to enable flexibility in low voltage networks in Germany

Based on the outcomes of the final use case demonstrations and the technical and regulatory analysis of previous chapter we recommend a set of actions to enable more flexibility in low voltage networks for the access of the DSO.

8.3.1. Simplify the rules for domestic energy storage to encourage participation in flexibility mechanisms

We gave a detailed description of why the current regulatory framework in Germany is hindering the participation of domestic ESS in flex mechanisms. We recommend simplifying the rules in such a way that it becomes easy for any owner of an ESS to offer flexibility to third parties. We acknowledge the reasoning behind the existing rules to be well-intentioned. However, we also advocate that useful flexibility offered by domestic ESS is of greater value to the system.

8.3.2. Expanding on the control of heat pumps

Heat pumps have proven to be a big potential source of flexibility in low voltage networks. The activation is nowadays limited by contractual agreements between DSO and the customer. It should be possible to expand on these limitations whenever more flexibility could be offered without impeding the customer's comfort. If, for example, the customer's installation contains more thermal inertia, it should be possible to interrupt operation for longer than 2 hours at a time.

8.3.3. Explicit acknowledgement that double-tariff-customers can be used for the benefit of the DSO

As shown in use case 3 and beyond, there is tremendous flexibility in the double-tariff mechanisms of previous regulatory periods. While technically possible, it must be acknowledged by the regulators that these mechanisms can be used as part of an active flexibility management for the benefit of the grid.

8.3.4. Encouragement for DSO to implement advanced flexibility concepts

The concepts and technologies demonstrated in InterFlex must find their way into daily operation. The numerous benefits have been confirmed during field testing and technical feasibility has been proven during the demonstrations. What lacks is the acknowledgement of the regulator that investments and costs incurred to develop and maintain an active flexibility management are part of the DSO's regulated cost base and that these can be recovered via grid charges.

8.3.5. Allow DSO to add control boxes to smart meters at rollout and allow for the cost to be recovered via grid charges

The demonstrated technology and use case rely on the grid-wide deployment of smart meters in combination with a control box. The control box is crucial in this context because it enables all existing use cases to be migrated onto the new technology and control these via the Smart Grid Hub. As of today, the control box is not mandatory part of the smart meter roll-out in Germany and the allocation of costs is not clear.

8.3.6. Finalize the Statutory Law governing the utilization of small-scale flexibility by the DSO

It has been mentioned in previous chapters how the lack of clear rules and regulations on the activation of small-scale flexibility by the DSO is slowing down the development of flexibility management strategies and technologies. We encourage the German government to speed up the development and consultation regarding the statutory law concerning §14a Energy Industry Act. It should set out clear rules on how and under which circumstances DSO can activate flexibility, how to reimburse customers for the provision of flexibility and where the grid-centred activation ends and market-based flexibility mechanisms begin. It should acknowledge that there are economic benefits to allow DSO to leverage this kind of flexibility to improve and optimize operations.

8.3.7. Keep interruptible loads in the pool of reference profile customers to improve balancing and reduce costs

The current interpretation of the regulatory framework in Germany beyond the kick off of the smart meter rollout suggests that customers equipped with a smart meter can no longer be managed under the reference profile approach and instead have to be balanced based on their actual 15-Min profile. Essentially this move reallocates the responsibility for the forecasting error from the DSO to the TSO or retailer. It reduces the pool of customers accounted for via the reference profile model and hence reduces the coincidence factor among those, ultimately increasing the uncertainty on both sides. This uncertainty and fragmentation of the residential segment will lead to a reduction in the efficiency of balancing, because moving forward the same group of customers will be managed in two separate balancing circles. WP5 has shown clearly the potential benefit of keeping controllable loads in the reference model, as this flexibility will enable the DSO to significantly reduce the costs incurred for the balancing of the pool of reference profile customers. Therefore, it is strongly recommended to revisit the guidelines and laws governing the treatment of reference profile customers and consider whether customers with controllable loads can remain in the responsibility of the DSO.

8.3.8. Incentivizing the DSO to invest in Demand Response

Since the potential upsides outweigh the teething troubles of the demonstrated technology, it seems apparent that DSOs should be incentivized to invest in technologies that allow them to use residential flexibility in general and improve existing processes with it. Incentives might come in the form of political encouragement and acceptance of this new technology as part of a DSO’s regulated asset base. Crucial in Germany in this context is the financing of the control box. While the smart meter and SMGW are covered by separately regulated metering fees, the control box is currently not being included. Starting the smart meter rollout without a clear solution for the control box would be an enormous mistake because it would waste the synergies in installation costs. One possibility to solve this issue could be to accept the control box as part of the DSO operational infrastructure and its regulated asset base, and subsequently finance the control box via grid charges.

Regarding the application of flexibility mechanism it seems surprising at first how much might be possible even under today's regulatory framework. A new interpretation of the existing rules for tariff-switching and interruptible load already enable DSO to capture some of the value flexibility can bring to the system. Clearly policy makers should aim at encouraging this new interpretation and make sure that new regulation improves on what is being demonstrated today. At all costs, it should be avoided to discontinue the existing mechanisms without a clear path on how to continue the use of flexibility.

9. CONCLUSION

InterFlex set out to demonstrate a fully integrated approach to enable DSOs to directly control LV-connected flexibilities. The development and implementation of the Smart Grid Hub were successful, and all interfaces required to achieve seamless integration were designed, built and tested. As such, InterFlex delivered the blueprint for a flexibility management platform in Germany that takes full advantage of the national smart meter framework.

By building on the smart meter, the concept significantly lowered the installation costs for flexibility. Once the SGH is in place, the connection of new flexibility does not require any additional equipment. This lowers the barriers for the utilization of flexibility, increases customer acceptance and improves the economics of flexibility-centred use cases in the distribution network.

The use cases that were demonstrated focused on DSO-direct control and were based on mechanisms that are enabled by the regulatory framework today already. While the curtailment mechanism is only temporary in its nature, the capabilities developed will benefit DSOs regardless of the design of a control or curtail framework. If necessary, the SGH could just as well be upgraded to serve in a more complex and market based approach such as the soon to be introduced redispatch scheme in Germany. The SGH demonstrated how even a very simple demand response concept can yield big efficiency gains, if installation costs are kept to a minimum and a high degree of automation is achieved.

From a regulatory perspective it is surprising how much value even simple concepts can deliver. By interpreting existing concepts in the German context to improve the availability of flexibility for the DSOs, InterFlex could already show significant gains in efficiency and DSO economics. This should encourage regulators and DSOs alike to start working towards more flexibility sooner rather than later and not get hung up on finding the most advanced solution from the start. Starting with simple concepts that can develop into something more complex is a promising way to support and accelerate the growth of renewables.

Still, some regulatory barriers remain. Good examples were discovered when InterFlex tried to connect residential batteries and EV chargers to the use case demonstrations. The use of batteries is being hindered by a complex and restricting regulatory framework that puts emphasis on behind-the-meter flexibility and does not encourage the offering of in-front-of-the-meter flexibility. For EV chargers, the lack of a clear set of rules of when and how DSOs could interfere with consumption prevents these devices from participating in flex schemes and use case testing. These are just two examples, how a lack of regulatory certainty prevents the further development of desirable use cases for flexibility in the distribution system. At this point, we have solved the basic technical questions of how to implement a flexibility mechanism. The practical application of these use cases remains unclear and cannot be investigated further until the regulatory ground rules for activation and participation have been defined in more detail.

The way forward is three-fold. On the technical track, there remains the challenge to further investigate the cyber-security considerations concerning the coupling of IT- and OT-systems. Once the rules for the flexibility activation emerge, use case algorithms can be improved and refined to maximize benefits and impact.

On the commercial track, the first indications on cost-benefit-analysis remain to be investigated further. A changing regulatory framework as desired in general will naturally change the basis for the cost benefit analysis.

From an operational point of view, the developed technical solutions must now be synced and integrated into existing processes. Avacon is committed to continue the operation of the system and strives to develop the solution step-by-step and along with regulatory changes towards a productive system which can deliver savings and performance gains in the distribution network.