Flexible Heat and Power, connecting heat and power networks by harnessing the complexity in distributed thermal flexibility

D1.1. Business case analysis and business model development

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Table of content

This project has received funding from the European Union's Horizon 2020
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research and innovation programme under grant agreement No 731231

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 731231

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731231

List of tables

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 731231

List of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731231

This project has received funding from the European Union's Horizon 2020
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This project has received funding from the European Union's Horizon 2020
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Glossary

Actor

An (UML) actor models a type of role played by an entity that interacts with the subject, e.g., by sending and receiving messages.

Business case

A (UML) business case or business use case is a representation of how different roles can interact, i.e., create, trade and exchange services, to the end of creating value. The linkage is known as a value network. Business cases can be used for business modelling to elucidate software requirement.

Business model

A (UML) business model is a realization of a business case, translating it into monetary flows between concrete actors, subject to concrete national regulations. The purpose of a business model is to support the evaluation of the corresponding business case and asses its cost-efficiency.

Business value

Anything with a positive impact on the health of the business in the long run, e.g., knowledge, monetary assets, sales channels, technology, etc.

Flexibility

Flexibility is the ability to deviate from an expected energy demand or supply in response to an external signal, e.g., a price change or an explicit request.

Flexibility user

An entity that utilises flexibility as part of its business process.

Imbalance settlement

Imbalance settlement is the process of settling the individual imbalances incurred by each Balance Responsible Party (BRP), i.e., how much each BRP should pay or receive in compensation for its deviation from the previously submitted energy programme and the actual consumption as measured by meters at the portfolio connections over the Imbalance Settlement Period (ISP). Typically, the BRP pays or receives compensation per MWh, effectively excluding smaller actors from the imbalance market. The imbalance price can be negative, and for *dual pricing*, the price can moreover depend on the sign of the deviation.

Programme responsible party

The role responsible for the energy programme, i.e., the programme specifying the amount of energy each connected party expects to feed into and taken out of the grid over the day.

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Role

A (UML) role is a function that can be performed by a stakeholder as part of a business interaction. The same role can be played by different stakeholders depending on their willingness to act in accordance with the role.

Stakeholder

A (UML) stakeholder is a person, group or organization that has an interest in a business.

Use case

An (UML) use case is a list of actions or event steps describing the interactions between a number of actors to the end of achieving a goal.

Abbreviation	Full name
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
CHP	Combined Heat and Power device
COP	Coefficient of Performance
DA	Day-Ahead
DAM	Day-Ahead Market
DCM	Dynamic Coalition Manager (extension/specialisation of Aggregator)
DER	Distributed Energy Resource
DSO	Distribution System Operator
EV	Electrical Vehicle
ID	Intra-Day
IRR	Internal Rate of Return
ISP	Imbalance Settlement Period
IT	Information Technology
MS	Member-State
NPV	Net Present Value

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OTC	Over The Counter
PCC	Point of Common Coupling
PTU	Programme Time Unit
RES	Renewable Energy Source
T&D	Transmission and Distribution
ToU	Time-of-Use
TSO	Transmission System Operator
UML	Unified Modelling Language
USEF	Universal Smart Energy Framework (www.usef.energy)

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1 Introduction

1.1 About FHP

The FHP project[2] – *Flexible Heat and Power: connecting Heat and Power networks by harnessing the complexity in distributed thermal flexibility* – was submitted under the call *LCE-01-2016-2017: Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network*, more specifically under the *Synergies between Energy Networks* area.

The FHP concept is to use **distributed thermal flexibility**, such as provided by heat pumps in buildings, or large thermal storage solutions, such as the one provided by the Ecovat system, to make most effective use of available renewable energy, and to create the conditions to increase the amount of such renewable energy sources also at distribution system level.

We specifically focus on **RES curtailment mitigation**, i.e. minimizing curtailments of temporary excess RES generation that would result in either **market based** (economic reasons) or **grid related** (technical reasons) curtailment. For this, distribution grid connected thermal flexibility will be used, making optimal use of – but not surpassing – the distribution grid capacity. This requires that we:

- **Learn the flexibility**: adopt grey-box building modelling approaches to achieve a high level of replicability without or with minimal human expert intervention.
- **Manage the flexibility:** aggregate distribution grid connected thermal flexibility into **Dynamic Coalitions**[3] of flexibility, and interact with grid/system operators for either providing them a **local grid service** (e.g. preventing or solving congestion or voltage problems), or for providing a **system service** (e.g. balancing) making optimal (maximal but secure) use of distribution grid capacity.
- **Interface the flexibility:** developing a **multi-agent framework** connecting all stakeholders and systems, needed for the targeted services / use cases, and aligned with the ongoing work in the Smart Grid Task Force and its Experts Groups in the field of **standardization** in general and flexibility management specifically

1.2 About this document (structure/objective)

This document lays the foundation for the projects development activities in the RTD work packages.

It starts with an **analysis of the RES curtailment mitigation business case**: what is the problem that we want to solve, what are the prime (business) roles/actors (beneficiaries) that are affected by this problem, and what are the key elements that determine the potential value hence business case of our proposed solution. From this, **three Business Use Cases** will be defined.

We will then describe the prime beneficiaries for these Business Use Cases related to activating thermal flexibility instead of RES curtailment (*Value Driven Design*: avoided compensation costs or increased revenues for whom), as well as additional enabling roles/actors that are needed to

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[2] See http://www.fhp-h2020.eu/ and http://cordis.europa.eu/programme/rcn/700614_en.html

[3] Participation of the P2H resources is voluntary, and they have the freedom to decide when, how much, and for what incentive they offer flexibility. So, there is a dynamic pool of flexibility providing resources that each have a dynamic flex offering.

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effectuate the proposed Business Use Cases. After that we will describe the technological opportunities and functionalities that are available and needed for using thermal flexibility provided by distributed Power-to-Heat resource as a RES curtailment mitigation solution (*Technological Driven design*).

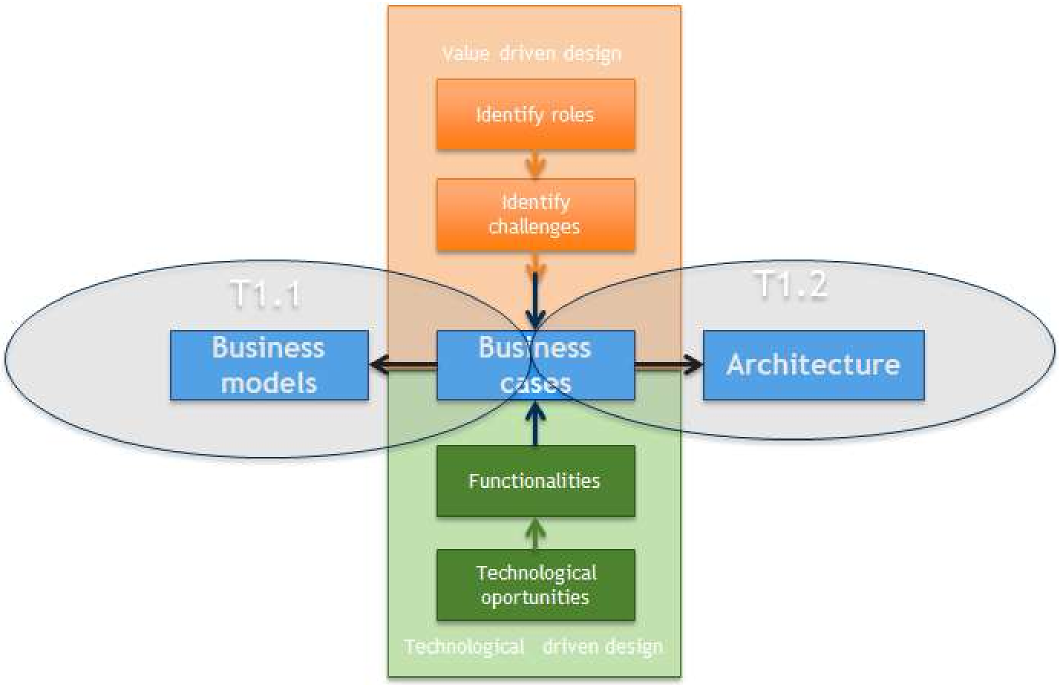

Figure 1: WP1 Methodology.

This will be followed by a detailed use case description of the tree Business Use Cases, based on the IEC 62559 Use Case methodology and template.

For the quantitative business modelling (i.e. all monetary exchanges between roles/business actors), the E3value methodology will be used which will be briefly explained in the next chapter. For each of the four Business Use Cases, an E3value model will be provided that will be the basis for further business cases analysis (for different contexts and scenarios) later on in the project.

We will conclude then with a brief description of required functionalities and conceptual information exchanges as identified in the Business Use Case descriptions. These will form the basis for the functional architecture and detailed design and implementation in the R&D workpackages.

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2 RES Curtailment Mitigation Business Case Analysis

2.1 Methodology of the analysis

The present report makes use of available literature on current market, operational and regulatory approaches on RES curtailment to, in a first stage, characterise the current and possible future context of European power systems and, in a second stage, illustrate the technical and economic potential that flexibility-based services could have to reduce the volumes of spilled energy from intermittent , wind and solar, RES.

The characterisation of these services followed the Use Case methodology, a proven method that particularly fits within the smart grid context and which is widely promoted in Europe and abroad by Standards Development Organisations (SDOs). As described in [1], the European Commission, SDOs, and business actors in the smart grid community agreed on the fact that the methodology is the best candidate for the description of a complex system like the smart grid. This methodology is designed to describe requirements of a given system (e.g. whole electric power system) or domain (e.g. distribution grid management domain), according to different layers, and ultimately facilitate interoperability. ENTSO-E, for example, uses it intensively to describe market business processes and network codes requirements. For more information on how to implement the Use Case methodology on the definition of flexibility-based services within a smart grid context see [1], [2].

This report (D1.1) focuses on the business layer of the use case (service).[4] That is, the description and illustration of roles and relationships envisioned for the provision of flexibility-based services in the context of the FHP project. The system layer of the use cases are described in deliverable (D1.2).[5] The description of the business and system layers is used in the definition of key performance indicators (KPIs) assessing the performance of the pilots. As a result of the project, advice to regulatory authorities and commercial players will be issued concerning the relevant services. These recommendations will take into account the peculiarities of each system, and the current regulatory vision as well as its expected evolution.

The FHP project uses the Smart Grid Architecture Model (SGAM) model as a guideline for the description of such flexibility-based services. This deliverable focus on the first layer, i.e. Business layer, as shown in **Figure 2**. The approach followed in this project aims at describing services that are replicable and scalable. In this manner, the FHP project moves forward to implement services that are valuable for the power system, especially distribution networks, across Member States (MS) within the smart grid context.

[4] Three business use cases have been identified within WP1.

[5] Deliverable D1.2 describes the function and information layer.

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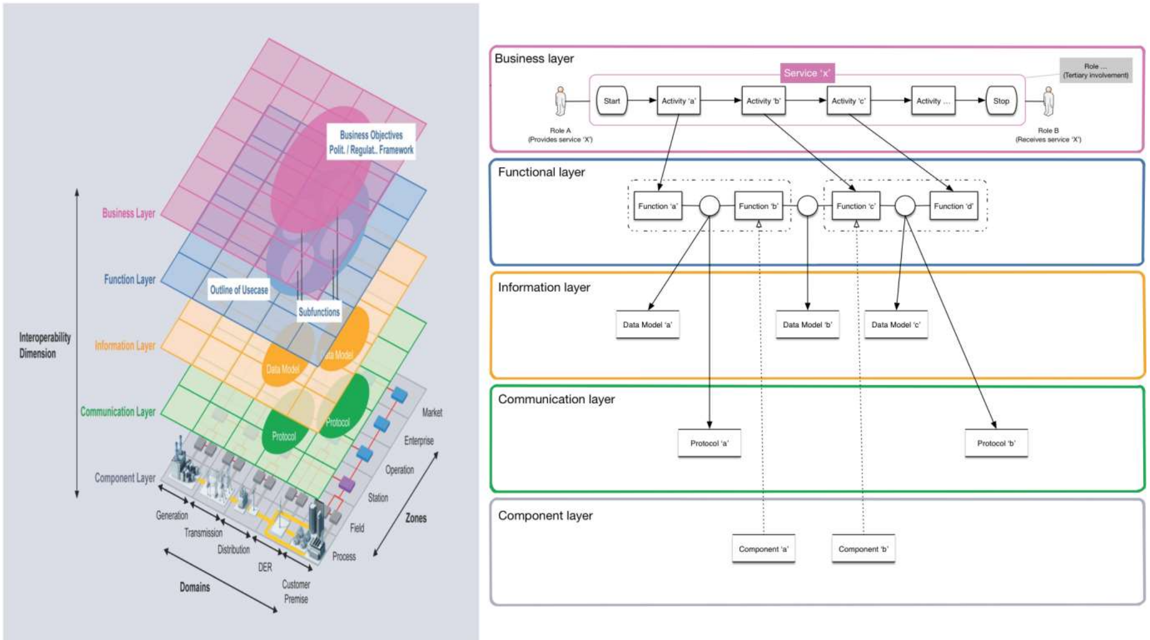

Figure 2: Mapping of the business and functional layers to the FHP project.
Source: Own creation.

2.2 Introduction

Transmission power systems in general, and distribution power systems in particular, are undergoing a structural transformation. For distribution systems, this is in large part driven by the increasing share of distributed Renewable Energy Sources (RES).

According to [3], the share of distributed RES in European distribution systems is particularly significant, with some Member States (MS) producing more than 20% of national electrical energy consumption from RES connected to distribution systems. The study also shows that the share of distributed RES will increase significantly in the coming years. Note that according to 2012 data it is expected a strong increase of PV generation capacity across the evaluated[6] countries and scenarios.

Empirical data confirms this expectation. In Europe, for the period 2000-2017, intermittent renewable generation capacity such as wind and solar PV showed a steep increase[7] while fossil-fuelled capacity decreased and hydro capacity remained flat (**Figure 3**).

[6] The evolvDSO project (evolvdso.eu) has evaluated a set of European countries. Among these countries were Belgium, Germany, France, United Kingdom, Ireland, Italy, Portugal.

[7] Trend observed for wind since 2000 (green dashed line) and for solar PV since 2008 (yellow dashed line).

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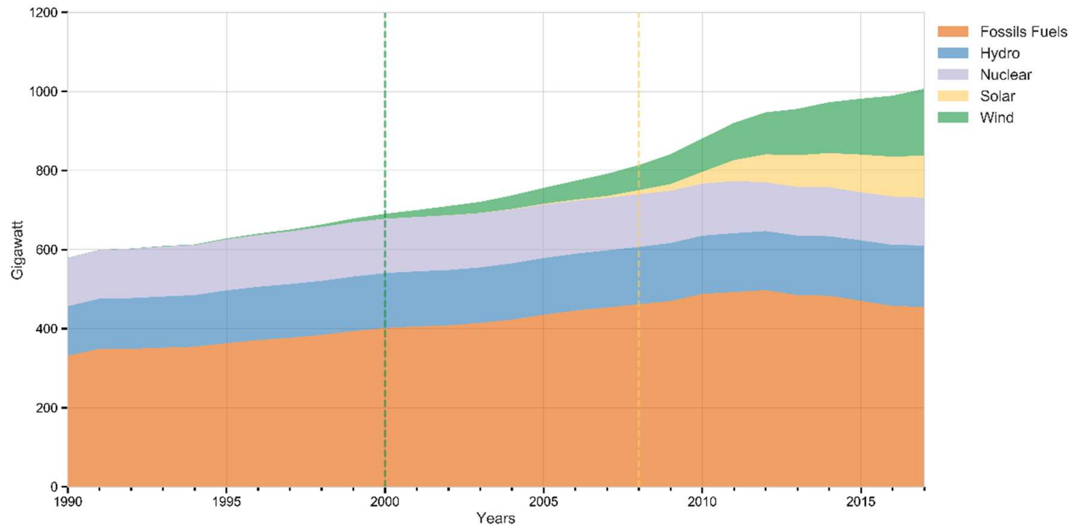

Figure 3: Generation capacity in Europe (EU-28).
Source: Eurostat[8]

Concerning new installations, renewable power has been steadily added to the generation mix (***Figure 4***). In 2018, renewable energy accounted for 95% of new installations of power capacity [4]. Wind and solar PV totalled 88% of the new renewable installations.[9] According to WindEurope [4] the net growth of RES (mainly wind and solar PV) has coincided with a net reduction of conventional generation (mainly fuel oil, coal and nuclear) as can be seen in ***Figure 5*** (period 2000-2017) and ***Figure 6*** (2018). ***Figure 7*** shows the distribution of the European energy mix in 2017 as a result of this trend.

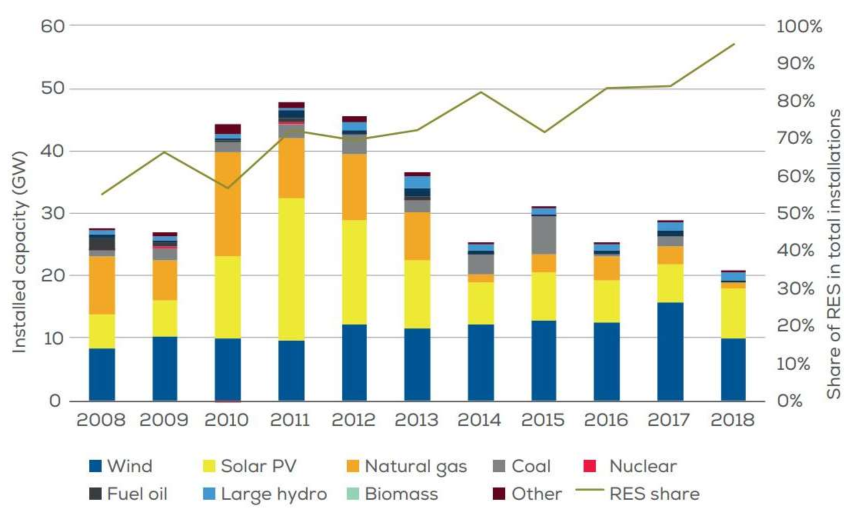

Figure 4: Annual installed capacity and renewable share (EU-28)
Source: WindEurope [4]

8 Eurostat database [nrg_inf_epc]. Last updated in 03-07-2019.
9 In 2018, 10.1 GW and 8 GW of wind and solar PV power capacity were installed, respectively. [4]

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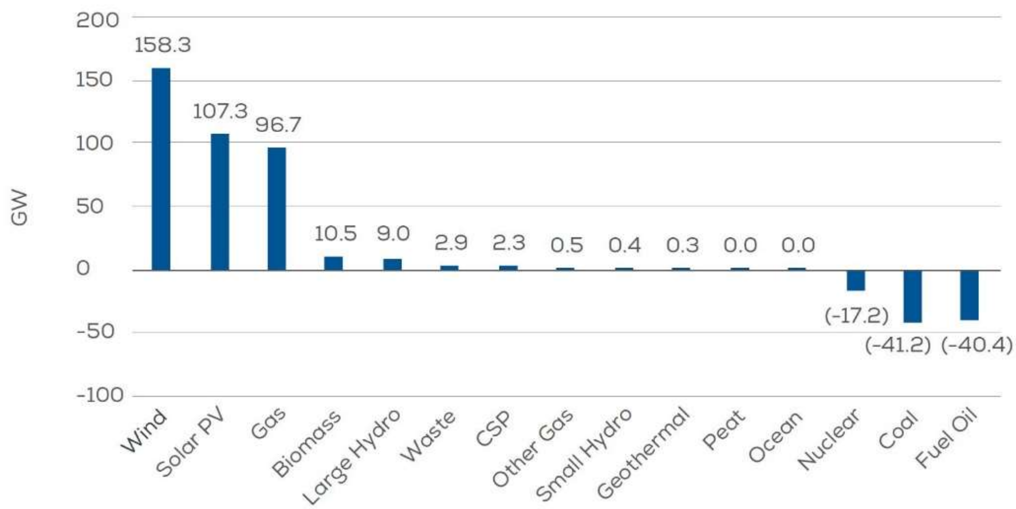

Figure 5: Net electricity installations in the EU from 2000 to 2017
Source: WindEurope [5]

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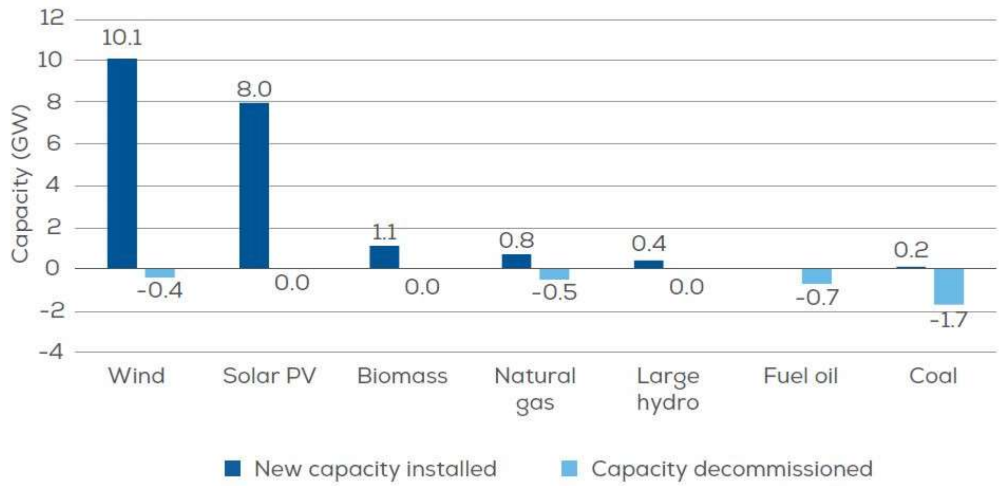

Figure 6: Installed and decommissioned capacity in EU-28 (2018)
Source: WindEurope [4]

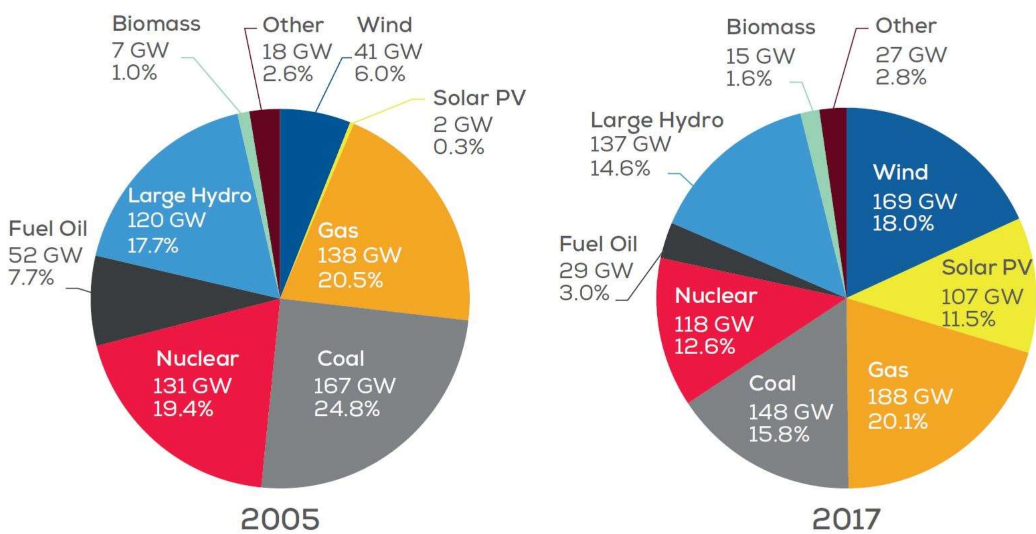

Figure 7: Share in installed capacity in 2005 and 2016.
Source: WindEurope [5]

This trend is expected to continue due to strong support from policies and targets at EU and national levels.

In 2007, EU Member States agreed upon a set of climate change targets for the year 2020. These targets were enacted through the Climate and Energy Package in 2009. The so called “20/20/20 targets” consist of a trinity of objectives:

- 20% reduction EU greenhouse gas emissions (in comparison to 1990 levels)
- 20% improvement EU energy efficiency

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- 20% EU energy consumption produced from renewable sources

In 2014, the EC released the 2030 policy framework [6] strengthening these targets:

- 40% reduction EU greenhouse gases
- 30% improvement EU energy efficiency - supported by the energy efficiency directive (2012) [7]
- 27% EU energy consumption produced from renewable sources

2020 and 2030 targets are in line with the commitment of the EU to keep climate change below 2 degrees Celsius by reducing 80-95% greenhouse gas emissions by 2050 [8].

In 2017, RES represented 17.5% of total energy consumed by EU members. Clearly, national efforts are already providing results. Some member states (MS) have achieved their national target. For other MS, efforts are still to be materialised (***Figure 8***).

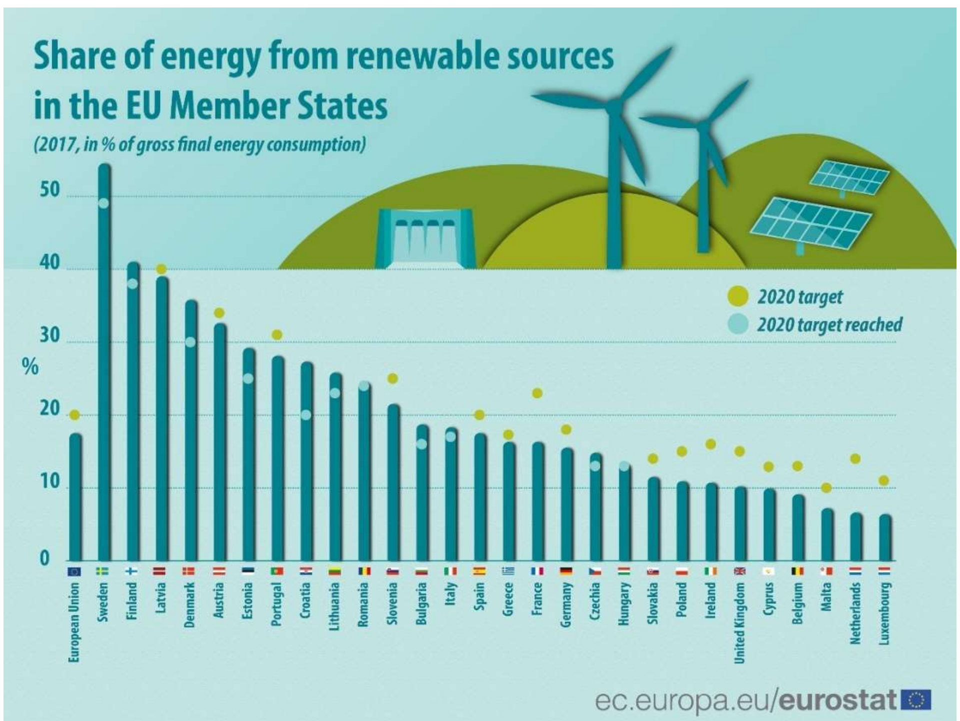

Figure 8: Share of energy from renewable energy sources in the EU MS (in % of gross final energy consumption).
Source: Eurostat

Zooming in, wind and solar PV have been increasing across MS. In 2017, the share of wind and solar PV power comprised more than 20% of the power mix in ten MS (***Figure 9***).

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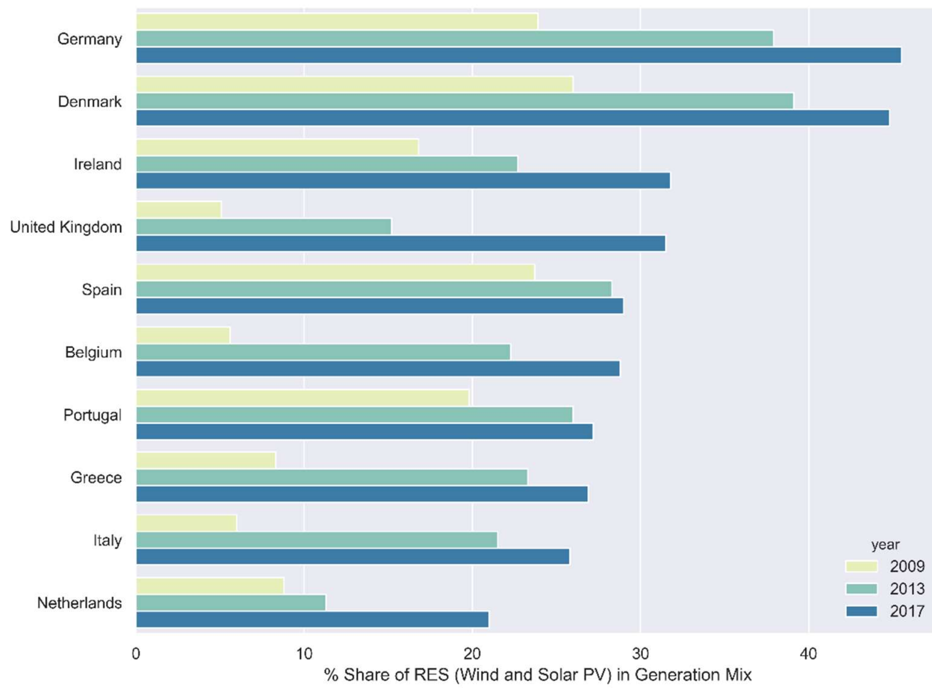

Figure 9: Share of intermittent renewable capacity (wind and solar PV) in the generation mix

Source: Eurostat[10]

Under the current design of the power system, the increase of intermittent renewable generation tends to reduce the flexibility of the grid to transport and distribute fluctuating inflows in a cost-efficient and secure manner. Across the literature, it has been highlighted that the integration of current and future variable renewable generation capacity presents a number of planning and operational challenges, especially for distribution system operators (DSOs) [1], [9]–[15].

Increasing volumes of intermittent, consumer-owned, distributed and non-dispatchable renewable units for electricity generation increments the uncertainty in the power system. The level of uncertainty varies according to the scale at which these resources are distributed (resources in a constrained area, although uncertain, show similar behaviour). According to the magnitude of the fluctuations the stability of the grid may be jeopardised. In distribution grids a number of operational problems may arise during periods of high intermittent renewable generation and low demand such as voltage variation (i.e. rise), degraded protection, altered transient stability, reverse power flow, and increased fault level [12]–[14].

Among the actions the DSOs can take to tackle RES integration challenges are grid reinforcements, apply control and automation strategies (e.g., voltage management) and systems (e.g. Distribution Management System - DMS, Distribution Automation Systems - DAS), make use of active demand and/or storage facilities, and curtail RES feed-in. From a techno-economic point of view, reinforcements are effective but costly. Storage units also might not be a cost-efficient solution if their investment is solely based on the absorption of RES surpluses. RES curtailment could be an attractive

[10] Eurostat database [nrg_inf_epc] and [nrg_inf_epcrw]. Last updated in 03-07-2019.

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option since it can be activated only when needed, just as active demand (demand response). However, as stated by [14] "the choice of the optimal solution is not straight-forward."

From the options to tackle these challenges, one is of utmost importance for the FHP project: the cost-efficient management of events in which the grid is limited in its capability to integrate renewable generation in-feed. In the context of the FHP project, curtailment events will be reduced with flexibility provided by buildings or an Ecovat system (demand response). By doing so, the FHP project would be providing alternative options, in form of services, to RES curtailment which is likely to become more frequent with the increase of RES generation capacity. These services could be used by network/grid operators and DER Producers to optimise their investments. But also by Balance Responsible Parties (BRP) to manage their financial positions (portfolio management) minimising deviations from the scheduled (generation and consumption) programs due to the nature of the resource (i.e. variability of wind and solar) or to (external) factors that distort market dynamics (e.g. network technical constraints).

2.3 What is RES curtailment?

This deliverable uses the definition of curtailment as stated in [15]. In general terms, curtailment is understood as ***a limitation imposed to generation units on their maximum output (below each unit's maximum in-feed) for a period of time in which the system cannot accommodate all variable renewable generation in a secure manner***. That is to say, curtailment is an "instance when a generation unit produces less than it could due to its own marginal cost characteristics" [15]. Therefore, for the purpose of this deliverable, references to limiting the output of generation units should be interpreted as "RES curtailment".

In general, curtailment events may be driven by market forces (market-based curtailment) or by grid-related issues (grid-related curtailment) [10]. The former can be understood as the "behaviour to restrain from bidding". This occurs when DER Producers have low or no incentive to offer their energy production in the market. For instance, in the presence of negative prices.[11] The latter can be understood as instances where network constrains and/or other factors threaten grid stability and limit the capability of the grid to securely integrate RES. Grid-related issues may appear from day-ahead (e.g., network constraints) up to real-time (e.g., frequency problems originating from fast changes RES generation, grid faults).

Table 1 shows both market-based and grid-related types of curtailment along with their components and drivers.

		General classification	
		Market-based	Grid-related
Voluntary	Driver	Economic	Economic & technical
	Decision	Market player based on economic assessment	Grid operator & market player based on a techno-economic assessment
	Rational	Minimise losses	Optimise investments and grid operation

[11] A combination of factors may lead to the occurrence of negative prices. Among these factors are the presence of high-shares of RES, reduced energy demand, inadequate technical capabilities of power plants and the existence of contractual obligations [10].

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Involuntary	Driver		Technical
	Decision		Grid operator based on technical assessment
	Rational		Maintain system security

Table 1: Curtailment - general classification and components
Source: based on [15], [16]

Curtailment may be triggered by a number of reasons and could have a voluntary or an involuntary[12] component (*Figure 10*). This report briefly explores four reasons for curtailment, namely network constraints, network security, excess generation relative to load levels and strategic bidding.[13] More details concerning these reasons can be found in [15].

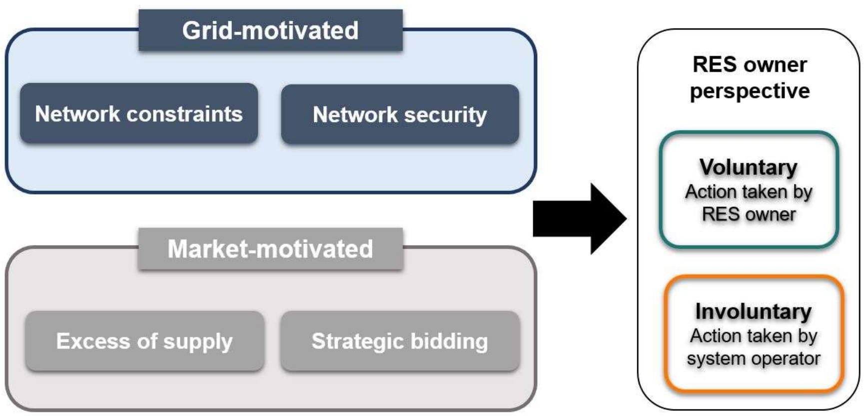

Figure 10: Different motivations for RES curtailment nad the perspective of the RES owner

Voluntary curtailment may involve an explicit agreement between the network operator (for subjects relating to grid operation and security) or a market party and the renewable energy unit owner, where the latter agrees to reduce the unit's in-feed in exchange for compensation. However, it may also occur if the generator is maximising his profits based on the constraints he is facing (e.g., negative prices) or to increase short-term profits.

Involuntary curtailment, in the other hand, takes place without an explicit arrangement between the network operator and the owner of the renewable energy unit. This type of curtailment is initiated by the network operator for operational and security reasons (more frequently due to network constraints).

In the following section instances that trigger RES curtailment are provided.

[12] As it can be expected, involuntary curtailment is still the focus of current discussions due to its environmental implications (e.g., waste/spill of clean energy)

[13] RES in-feed, specially wind, may also be curtailed for other reasons. For instance, to protect wind turbines during strong winds or storms or to comply with the shadow flicker criteria at nearby dwellings. However, these situations are of less interest for the project since the turbine has to be stopped leaving no option for storing the energy.

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2.4 Curtailment instances

Curtailment of RES is still a controversial subject due to its environmental implications. While this option may prove optimal in respect to total costs of providing electricity [15], it probably should be considered as a last resort to allow for the exploration of all other flexibility options [17], [18]. This is in line with the explicit request made by the EU to all member states in [19] "*to ensure that appropriate grid and market-related operational measures are taken in order to minimise the curtailment of electricity produced from renewable energy sources.*"

As introduced earlier, reasons that may trigger RES curtailment are:

- Network constraints *(a)*
  - Congestion at transmission and distribution systems
- Grid security *(b)*
  - Specially frequency response following the loss of the largest in-feed that create rates of change of frequency larger than what currently generators are oblige to comply according to the grid code
  - Inadequate transmission and distribution system capacity
- Limited demand in combination with excess of generation *(c)*
- Strategic bidding *(d)*

So far it has been stressed that instances in which RES generation is curtailed are not necessary driven by grid design or grid management approaches, but also by the design of the electricity market and the behaviour of its stakeholders [9], [10], [15], [17]. In the following, instances for each case are introduced distinguishing between voluntary and involuntary curtailment.[14]

In the case of insufficient grid capacity (a) to evacuate RES feed-in (i.e., the network is constrained), voluntary curtailment may be used by RES owners to get a faster or cheaper connection. In contrast, involuntary curtailment may be used by the system operator to optimise network investments. Both types of curtailment are possible due to a development mistmatch (maximum planned or current RES feed-in is larger than what the grid can handle at the connection point).

An example of voluntary curtailment is a RES owner that receives a connection capacity lower than the total nominal generation capacity of the connected units. This limitation may be fixed (lasting the entire life of the units) or variable (set for a limited period). For instance, offshore wind installations in the UK or RES owners subscribing to a non-fixed connection contract with the system operator.

An example of involuntary curtailment is when the system operator limits RES infeed in real-time for a limited period. For instance, to manage congestions in Germany (Northwest).

In respect to network security (b), a RES owner may voluntary curtail the in-feed to support the system (which is in need of short-term flexibility) in exchange of a retribution. Windfarms participating to downward tertiary reserve in Spain exemplify this type of curtailment. In contrast, involuntary curtailment may be enforced by the system operator to maintain a certain system reliability level, e.g., to maintain a certain level of inertia or to protect against the "duck curve" effect. An example of this measure is the dispatch-down of windfarms in Ireland. It is worth noting that voluntary curtailment due to network security is impacted by market forces (in this case, the interplay between prices at

14 Based on the perspective of the RES owner.

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wholesale and balancing markets). Conversely, involuntary curtailment due to network security is less impacted by market forces and more affected by AC power system fundamentals. That is, the reason to maintain certain units online (e.g., fossil-fueled generators) is to provide the system with services not traded in markets even if that means having these units running at a set point that is not optimal in terms of generation costs.

In the events of network constraints requiring real time curtailment of RES infeed, low inertia levels, and excess of generation in respect to demand[15], it is the network operator who takes the decision to curtail the renewable in-feed.

In Europe, curtailment volumes, under these reasons, may reach a considerable share of the total energy produced by renewable units [20]. ***Figure 11*** shows the percentage of energy loss due to wind curtailment between 2010 and 2012.

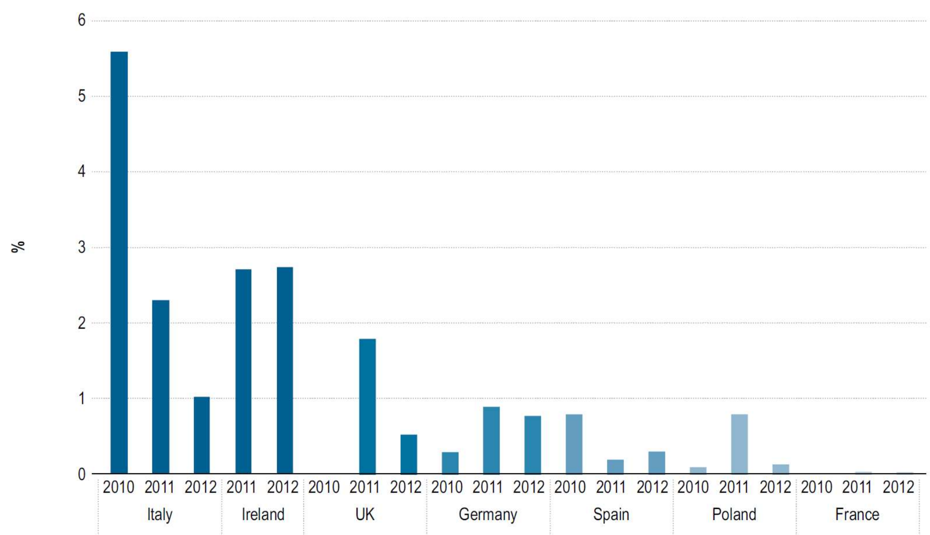

Figure 11: Percentage of energy loss due to wind curtailment between 2010 and 2012. Source: [20]

To some extent, grid-related curtailment of wind occurred due to a combination of low demand and excess of generation in the control area [20]. According to BNetzA [21], in Germany, most of the limitation actions (98 %) took place in the distribution grid. Out of the total energy curtailed in Germany for 2012, wind accounted for the lion's share (93.2 %) while solar PV reached 4.2 % [22]. For an updated picture of curtailment volumes see section 2.11.

Market forces also create instances for voluntary and involuntary curtailment (c & d).

Figure 12 exemplifies situations at which voluntary curtailment (of wind energy) may occur . As it can be observed, voluntary RES curtailment occurs on the flat parts of the price duration curve when prices reach zero or negative. In this case, the RES owner limits the infeed to reduce financial losses due to low market prices. Note that the decision to limit the infeed would be according to the applicable support scheme.

[15] When this leads to technical constraints.

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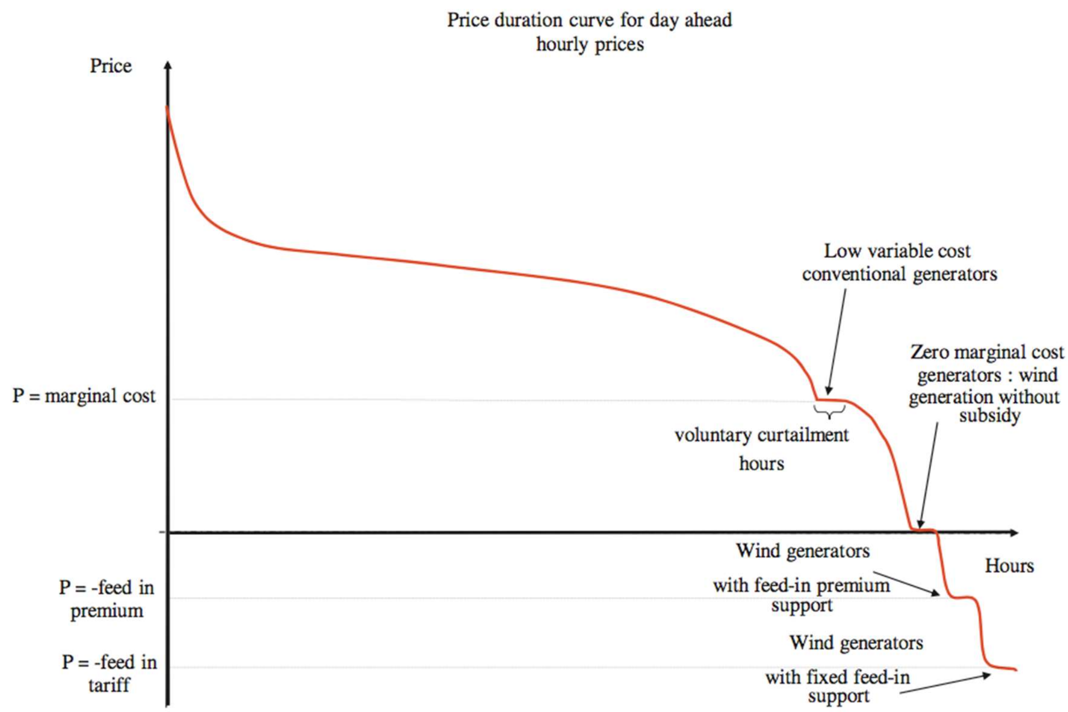

Figure 12: Voluntary curtailment and prices (generic annual price duration curve)
Source: [15]

Typically, market-based curtailments occur during periods of low demand (typically at night and in the morning) and high RES production.[16] That is to say, RES curtailment is frequently observed in the presence of low market prices. For instance, ***Figure 13*** shows that in 2013 the Spanish market registered zero prices[17]. According to [20] this can be attributed to an excess of generation in comparison with demand (at zero price, supply doubled demand).

[16] Some other factors should also have to be taken into account such as the number of inflexible units (e.g., Nuclear), etc.
[17] Minimum (floor) price in the Spanish electricity system.

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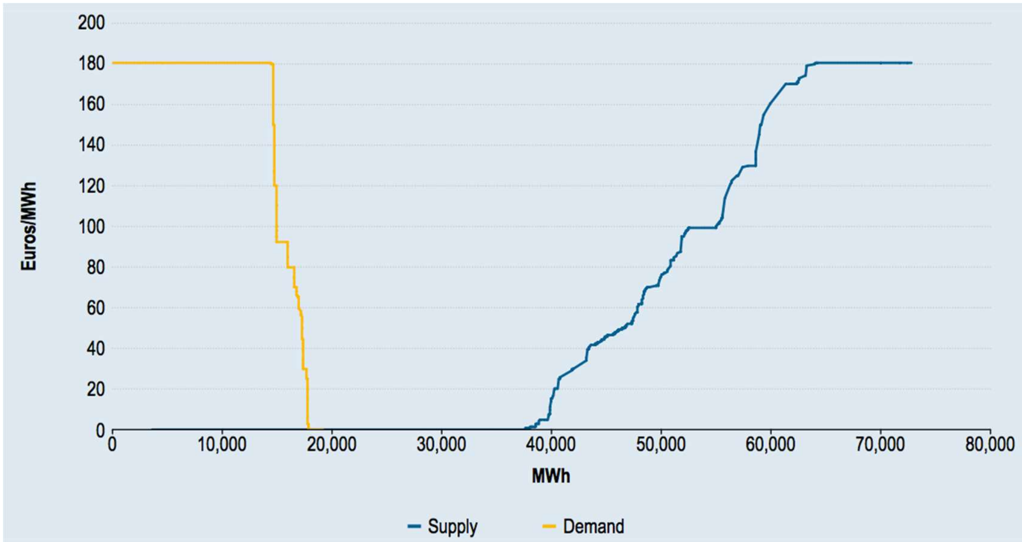

Figure 13: Zero price in the Iberian electricity market (29/03/2013, 6h - aggregated curves). Source: [20]

Involuntary curtailment may be used by the system operator to regain the balance between supply and demand. The intervention of the system operator is triggered by a security concern or a market failure. For instance, when downward reserve is exhausted the Spanish TSO curtails RES infeed through the real time congestion management procedure. This is used as a measure of last resort [16].

To increase short-term profits a RES owner (or his/her market representative) may withholds generation capacity to increase the marginal clearing price, i.e., decide to voluntary curtail RES infeed to manipulate wholesale prices. This strategic bidding (d) is possible if due to an imperfect market structure the market participant has market power and exercises it.

In summary, RES curtailment may be voluntary or involuntary. Curtailment actions may be motivated by the characteristics of the power system or by the market environment.[18] The former takes into account the physical reality of the grid and the operational approaches adopted by the system operator (e.g., amount of RES installed capacity and its capacity factor, the level of demand in the system at a given moment in time, grid capacity, the required minimum generation levels of conventional power plants, the topology of the grid). The latter considers curtailment instances due to excess of supply in respect to demand and opportunistic behaviour of market players (i.e., strategic bidding).

2.5 Relevance of RES curtailment

Optimal use of RES curtailment may improve energy efficiency, minimise market distortions and support efforts towards the decarbonisation of the power system [17]. In general, improving energy efficiency makes an essential contribution to all of the major objectives of EU climate and energy policies: improved competitiveness; security of supply; sustainability; and the transition to a low

[18] Note that due to the interplay between both, power system dynamics and electricity markets, RES curtailment may take place from planning to real time.

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carbon economy. This is in line with the policy framework for climate and energy 2020-2030 [6] and with current developments.

By 2020, as part of the "*Clean Energy for All Europeans*" package, also known as the "*Winter Package*", [23] the proposal for a regulation of the european parliament and of the council on the internal market for electricity (recast) [24] states that concerning curtailment "*producers of electricity from renewables or high-efficiency cogeneration will only be subject to curtailment if no other alternative exists.*" In case that curtailment is needed, financial compensation by the entity[19] requesting the curtailment will be provided. Moreover, system operators are encouraged to take measures to reduce downward redispatching of renewables and high-efficiency cogeneration [25].

In addition, the proposal for a directive on the promotion of the use of energy from renewable sources (recast) [26] states that "*the share of energy originating from renewable sources in the heating and cooling sector is supposed to increase by 1% each year. Consumers that are connected to a district heating or cooling system not meeting the efficiency criteria of directive 2012/27/EU will be allowed to disconnect from not efficient systems to produce heating or cooling from renewable energy sources themselves.*"

Both developments open the door for new business models providing flexibility services, such as the ones described in this project.

To minimise market distortions, [17] suggest compensating curtailment according to market-based principles in order to avoid missing money problems for curtailed units as well as discrimination (between resources). A discussion on potential compensation schemes for RES curtailment can be found in section 2.8.

2.6 Impacts caused by the use of curtailment

First and foremost, curtailment of variable renewable generation is a lost opportunity. It reduces the amount of clean energy to serve demand, and in some cases, involves a considerable share of energy loss (as illustrated in ***Figure 11***, this section and section 2.11).

However, limiting the maximum output of RES units during short periods may have some positive and negative impacts on the operation of the grid and as well on the interactions among stakeholders.

As positive impacts, RES curtailment may reduce grid investments needs and operational costs. More in detail, limiting RES feed-in could lead to an important reduction of investment needs as demonstrated by the study of the German Energy Agency (Deutsche Energie-Agentur) [27]. In this study, 30 % of the cost for distribution grid expansion may be saved if RES energy is limited to 70 % of the maximum power. Operational costs such as procurement of operational reserves and balancing energy may be reduced by curtailing RES feed-in so that related forecast errors have a lower impact on reserve provision.[20]

As of negative impacts, curtailing RES reduces their share on serving demand and increases the share covered by conventional sources. This leads to an increase of fossil fuel use, which in turn increases

[19] e.g. the system operator in case of grid-related curtailment

[20] Specially in the situation where system flexibility is low and RES variability is high as demonstrated in [9].

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CO_2 emissions. Additionally, reducing the use of clean energy by curtailing RES may create financial losses to DER Producers (if not compensated accordingly) and provide negative signals to investors. This in turn will hinder member states to achieve environmental targets and may also increase the likelihood of higher retail electricity prices [9].

The energy that is rejected by the system (in case of curtailment) could represent sizeable economic loss. For example, in 2013 a higher than usual wind energy generation was registered in the Spanish system (increase of more than 12% when compared to 2012 volumes). To resolve balancing issues and to overcome technical constraints Red Electrica de España (Spanish TSO) curtailed a large share of wind feed-in (2.14% out of the approx. 54.3 TWh produced in 2013) leading to an economic impact of around 85 million Euros[21] [20], [22].

Limiting RES feed-in for economic reasons may also reduce the incentives to innovate on technologies that could minimise its frequency and volume hindering their potential contribution to integrate variable renewable generation in a cost-efficient manner. Without innovative approaches like demand response (DR), power to heat (P2H) or power to gas (P2G), large investments in grid infrastructure and storage facilities will be needed to integrate the ever-increasing renewable generation capacity. Investments made with the sole purpose to accommodate RES feed-in peaks would be highly inefficient leading to a power system that is not cost-efficient. This is mainly due to the uncontrollability nature of RES, which create energy peaks that only account for a small number of hours within a year.[22]

Promoting research and development of innovative options may help to rise the market value of RES. For instance, by reducing its impact on the residual load (and by consequence on market prices) [10]. Moreover, P2H and heat storage solutions could be used to alleviate the need for combined heat and power (CHP) plants to bid below marginal prices,[23] which in turn could reduce market-based curtailment.

RES curtailment may take place even if innovative approaches are implemented. As stated by [15] "some curtailment of fluctuating (variable) generation is optimal" and "will increase along with an increased share of fluctuating renewable generation". However, it should only take place when marginal system cost of avoiding the curtailment are at par with the marginal value of spilling clean energy. In addition, the economic assessment should consider alternative and flexible options to integrate renewable generation into the system, such as optimal use of cross-border capacity in concert with market-based mechanisms that allow trading close to real-time. Furthermore, inefficiencies preventing cost-efficient utilisation of grid and generation capacity such as priority rules (priority of dispatch - introduced in EU directive 2009/28/EC) could be avoided since it distorts market dynamics and thus, short-term price formation [17]. This, in order for the most economic option to be implemented[24].

[21] According to the Spanish Wind Energy Association

[22] Although these periods will use the full capacity of the grid, for the most part of the year a certain amount of grid capacity will be idle (reducing grid capacity utilisation).

[23] To comply with contractual agreements. This behaviour in combination with other factors may create negative prices.

[24] Note that the derogation of such a priority rule would imply that RES units (energy) is treated in equal terms as other generation units. This will increase the risk at which renewable installations are exposed but also may lead to further developments on alternative flexible solutions.

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Steps in this direction can already be appreciated. To provide a level playing field for all technologies the EC has announced that RES technologies "will be subject to non-discriminatory third-party access rules."[25] [24], [25]

From a network perspective, implementing grid reinforcements to reduce instances of RES curtailment is an effective, but expensive solution to tackle issues arising from an excess of variable feed-in. In principle, the network operator[26] has the best knowledge about marginal grid reinforcement costs and marginal curtailment from adding more variable generation capacity. Given this case, [15] argues that RES curtailment compensation might be used as an incentive for the DSO[27] to invest in network capacity, especially in cases of asymmetry of information in favour of the DSO. The incentive should be such that DSO decides to invest when marginal network costs equal marginal expected compensation to RES unit over the life of the reinforcement.

From a theoretical perspective, curtailment should take place up to the point where the marginal cost of avoiding this curtailment equals the marginal value of spilled energy. Both the marginal costs of avoiding and especially the value of the spilled renewable generation, however, are difficult to quantify (*Figure 14*).

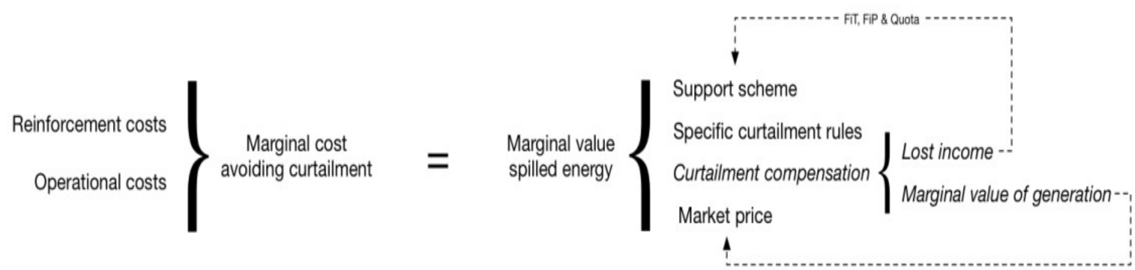

Figure 14: Theoretical perspective for curtailment decision.
Source: Based on [15]

2.6.1 Benefits to stakeholders

As seen, the use of RES curtailment could have operational and financial benefits. However, these benefits are driven by a set of key parameters, namely RES variability and system flexibility [9]. In a scenario where demand is not active in the power system, the relationship between these parameters determines the potential benefits consumers, dispatchable and variable renewable generation may obtain.

Table 2 shows the levels (of key parameters) at which stakeholders tend to benefit.

[25] However, priority dispatch will still be applicable to existing installations, small-scale renewables and demonstration projects .

[26] TSO or DSO

[27] Assuming the DSO is the one compensating the RES owner for the curtailed energy.

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		key parameters	
		System flexibility	RES variability/volatility
Stakeholders	Dispachable generation	High	Low
	RES generation	Independent	
	Consumers	Low	High

Table 2: Relationship between the level of key parameters and benefits to stakeholders.
Source: Based on [9]

Table 3 shows the tendency to over-/under-curtail according to the level of key parameters.

		RES variability	
		High	Low
System flexibility	High		Over-curtail
	Low	Under-curtail	

Table 3: Tendency to over-/under-curtail according to the level of key parameters for conventional generation and renewable energy generators.
Source: Based on [9]

From ***Table 2*** and ***Table 3*** it can be observed how the levels of system flexibility and RES variability favour a given stakeholder and how their interaction provides indications on the actions of generators concerning the curtailment volume.

Curtailing RES benefits dispatchable generation when system flexibility is high and RES variability is low. Since both generators (dispatchable and RES) are serving demand, the reduction of feed-in from RES tend to increase overall market prices. In this situation, generators may be incentivised to over-curtail (voluntary RES curtailment), especially when both types of generation belong to the same holding (strategic bidding) [9]. Please note that, as demonstrated in [9], RES generators may benefit from this situation even if no compensation is given (i.e., subsidy).

In contrast, consumers seem to favour when system flexibility is low and RES variability is high. This situation leads to low energy prices. In this situation, generators may be incentivised to under-curtail (which then could lead to a grid-related curtailment) driven by the value of the subsidy (e.g. Market premium).

According to [9] and [15] an optimal level of curtailment brings benefits to all stakeholders, even when RES curtailment is compensated. To achieve an optimal curtailment level, curtailment decisions should not be made in a decentralised manner since they tend to give sub-optimal results. Therefore, it is

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suggested that “optimal curtailment levels should be determined together with optimal network capacities.” In this way emphasising the role of network operators, especially DSOs which will have to integrate most of the variable renewable energy capacity [1], [3]. Given that a RES curtailment level is the trade-off between clean (renewable) energy and system flexibility[28], its optimal assessment is critical for the evolution of the power system.

2.7 Curtailment rules for renewable energy

In general, curtailment approaches could be classified in two groups: non-market based arrangements and market-based arrangements [28]. The first group uses predefined rules to curtail variable generation. Approaches within this group are set as grid connection requirements, and thus simpler to implement than market-based arrangements. That is, they require no changes to current regulation. Approaches in the second group use a market mechanism to settle curtailment order, prices and volumes for variable generation. In principle, this type of approaches may perform better than the non-market based ones since the economic signals regarding the cost-effectiveness of curtailments would be transparent. However, the implementation of these approaches may require modifications on current distribution practices and regulation, in addition to the definition of rules and structure governing the market.

In the following, curtailment rules for Belgium, Czech Republic, Netherlands, Spain and Sweden are presented.

2.7.1 Belgium

At system level, the TSO is responsible for the minimisation of RES curtailment[29]. At regional level (Brussels, Flanders, Wallonia), legislation differentiate between planned and unplanned curtailment [29]. Planned curtailments may be imposed by the DSO to a generation unit if the security, reliability or efficiency of the grid is at stake.[30] This type of curtailment requires previous communication with the affected plant operator. Unplanned curtailments may be imposed by the DSO in case of emergency, risk of grid operation and excess capacity. Compensation due to a curtailment event is not foreseen in Brussels, Flanders or Wallonia [30]. However, the modalities and arrangements for the interruption or access limitation are contractually agreed between the Flemish DSO and the electricity distribution network user or access holder [31]. Note that RES units (mainly wind) that participate in the reserve market (“free bids”) are bound to the rules of the market. Generators from which bids are selected reduce their feed-in to the system (voluntary curtailment).[31] [32]

[28] Including flexibility of generation and network assets.

[29] Art. 8 §1 no. 5c of Loi du 29 avril 1999

[30] Brussels (Art. 170, Arrêté du 23 mai 2014); Flanders (Art. IV.4.2. Technisch Reglement); Wallonia (Art.134, Arrêté du 3 mars 2011)

[31] Note that a reduction of the output of wind farms for balancing purposes results in a loss of green certificates (which are allocated on the basis of produced energy). Therefore, the price of the energy provided via the balancing should be higher than the opportunity costs.

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2.7.2 Czech Republic

According to the Energy Act, DSOs may limit, modify or curtail the power supply from generators in case of a capacity shortage or threat to the safe and reliable operation of the grid.[32] Rules for the operation of the distribution grid are determined independently by each DSO[33]. At the moment, RES curtailment is not a major issue in the Czech Republic. As of May 2011, all renewable installations with generation capacity above 100 kW are obliged to regulate their electricity and install the technical means necessary to enable them to be regulated by the system operator [33]. Czech distribution grid has ample capacity and is largely organised in mesh providing for redundancy. Additionally, the largest DSO in the country can remotely control loads from electric heaters, boilers and heat pumps[34]. Thus, RES curtailment instances are quite rare (even in the near future). According to [33], the amendment introduced by the parliament to the Czech energy act introduces financial compensation for unplanned RES curtailments.

2.7.3 Netherlands

In the Netherlands, grid curtailment could be due to (a) congestion management or (b) emergency. The former was introduced in 2010 as a reaction to grid capacity shortages and the increasing number of grid connection requests (mainly from RES). This congestion management model is essentially a market to allocate the limited amount of network capacity in case of congestion. With the publication of congested areas, the grid operator specifies the amount of energy to be curtailed for each area and invites connected installations (generation and load) to bid their curtailment price (per kWh). The procedure takes place day-ahead. Bid selection is based on cost-effectiveness (to the congestion in question). In case voluntary bids are not enough, the grid operator will enter into mandatory biddings. Bids selected under this scenario will receive the highest bid under the voluntary procedure [34]. The latter, is meant to be used to ensure grid stability and grid security. In case this curtailment is implemented no compensation is foreseen and also no difference is made between RES and conventional generation units. According to [34] emergency curtailment is very rare in the Netherlands. However, most Dutch provinces (9 out of 12) are currently experiencing or are expected to experience some sort of capacity shortage, which may increase the risk of intermittent generation capacity (wind and solar PV). Therefore, in June 2019, the Dutch Minister of Economic Affairs and Climate urged grid operators to improve their ability to manage congestions. Among the solutions proposed are financial rewards and electricity purchases. The legislative ammendments are expected to be introduced by 2020 [35].

2.7.4 Spain

In Spain, rules to curtail variable renewable generation are governed by operational procedures 3.2, Technical Constraints Resolution on Daily Programme, and 3.7, Non-Dispatchable Renewable Generation Programme [36]. These procedures describe the situations, rule and priority order for grid-related curtailment actions.

---

[32] Rules on emergencies in the energy sector and on energy dispatching set out in Decree No. 79/2010 & Decree No. 80/2010

[33] Currently, there are three major DSOs in the Czech Republic. Originally, these DSOs served as grid operator and BRP. Today, and despite the formal split of activities, links remain. For example, the state-controlled ČEZ.

[34] Currently, 600 MW can be adjusted by the largest DSO in Czech Republic.

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According to [36] and [37], after the day-ahead market closes technical restrictions caused by excess of energy are solved applying a pro-rata reduction of scheduled energy to the daily basic operation program (PDBF), resulting in the doable daily program (PDV). This is applicable to all producers which have previously presented bids at the technical restrictions market (all production units at the PDBF are obligated to present bids); starting with, dispatchable production units (respecting minimal production requirement), followed by, high-efficiency co-generation units, dispatchable renewable units and, non-dispatchable (variable) renewable units, respectively. Since December 2015, wind energy[35] producers can contribute to upward and downward technical restrictions.

The re-dispatch is calculated in two phases. In the first phase generators are re-dispatched to deal with technical constraints, and it is usually upwards. In the second phase they are re-dispatched, usually downwards, to recover the balance between generation and consumption.

The same rule (pro-rata) and priority order are used to solve technical restrictions in real time. However, it is noteworthy to highlight that depending on the temporal occurrence of the technical restriction, the limitation to the production will be applied to the scheduled energy in the PDBF or to the current production of the unit. That is, planned curtailments occur just after the day-ahead market gate closure while, unplanned curtailments occur in real time.

As stated in [36], curtailment compensation is as follows:

- Planned curtailment
  - First phase (re-dispatch under security criteria)
    - In case energy has to be limited (i.e. system operator requires to reduce the energy schedule programmed in the PDBF) no payment is foreseen. At this stage, no offer would be used to request a reduction on the program. Any downward modification on the generators' output would modify the corresponding program in the PDBF (i.e. program reductions are considered as cancellations on the corresponding PDBF program).
  - Second phase (re-balance supply and demand)
    - Paid depending on the price of the offers presented by the generators, and if the generator did not present an offer (although being obliged to), it is paid at 115 % of the corresponding hourly marginal price of the day ahead market.
- Unplanned curtailment
  - Compensated at the price of the offers[36] used to these purposes and which were presented at the balancing market and/or technical restrictions market (second phase).

Moreover, in the case presented bids are not sufficient to obtain a balanced supply/demand program, the TSO would have to schedule upward and downward re-dispatches. Energy re-dispatched upwards will then be compensated at 115% of the corresponding hourly marginal price of the day-ahead market.[37] Energy re-dispatched downwards will be remunerated at 85% of the corresponding hourly marginal price of the day-ahead market [36]. Generation units have to adapt their output, once the instruction to limit generation is received, within 15 minutes.

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[35] In Spain, wind producers have been pre-qualified ito offer this service.

[36] Offers for tertiary regulation complemented with offers presented for the resolution of technical restrictions.

[37] At intraday, re-dispatches for upward and downward energy will incorporate the corresponding hourly marginal price of the intraday session [36].

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2.7.5 Sweden

The current Swedish legislation concerning electricity and the electricity market dates back to 1990, and while the legislation has been amended, it remains much the same and does not address the issue of RES curtailment [38]–[40]. This is due to the strong presence of hydroelectric power on the Swedish energy market and, consequently, there are no specific rules concerning RES curtailment in Sweden. In practice, this means that new DER Producers are restricted to connect where capacity can be guaranteed. And while there are no regulations against agreements on RES curtailment, there is a limited demand and such agreements are rarely formed.

According to [22] curtailments in Sweden are mainly due to technical constraints (e.g., voltage problems). If reinforcements are needed to connect a RES unit, the costs are covered by the DER Producer. Due to this, voluntary curtailments may be seen at the connection phase (where the full potential of the installed capacity is limited to avoid paying for reinforcements). In addition, grid operators may curtail RES in-feed, e.g., at transmission level, in case grid reinforcements have not been completed and a line outage occurs, while at distribution level, in case voltage problems arise. At transmission level, this is done by sending a signal directly to the plan controller. According to [29], [40] the RES plant operator is entitled to a fair compensation if a grid operator orders him to modify the plant generation set-point. From the rules explained above it can be observed that only two (out of the five) countries, Netherlands and Spain, use market-based arrangements. These arrangements promote transparency and cost-efficient assessment of curtailment instances. However, as observed for the majority of countries (involuntary) curtailment practices/rules are "often not transparent" neither on the circumstances nor on the curtailment order and "not always" occur under cost-efficient criteria [17]. That is why, international agencies have highlighted the need for short-term improvements to existing policies in order to maintain system security. To promote cost-efficient integration of high shares of intermittent renewable generation, transparency on curtailment actions should be enhanced. In 2016, this was one of the points covered in the report to the G7 [41], where IEA and IRENA listed the need for "Clear rules for handling the curtailment of VRE generation facilities" as one of the no-regret options.

2.8 Compensation schemes of RES curtailment

Concerning compensation in case of curtailment, [42] highlights schemes used in some MS to compensate (wind) renewable generators (***Figure 15***).

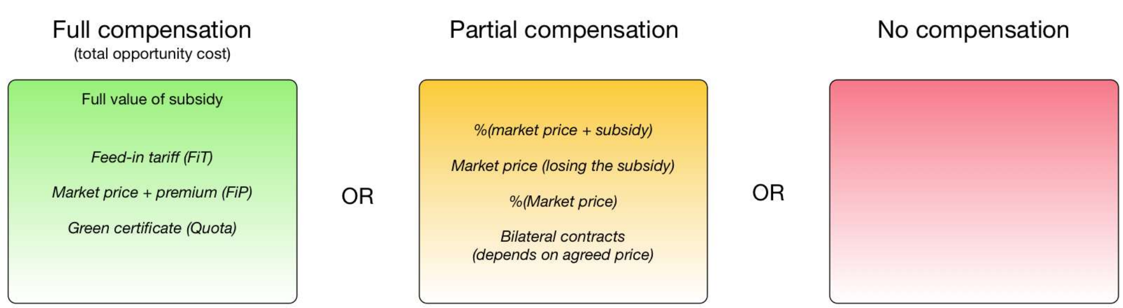

Figure 15: General compensation schemes.
Source: based on [42]

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Figure 16 illustrates potential instances that may result in a curtailment action and their suggested compensation.

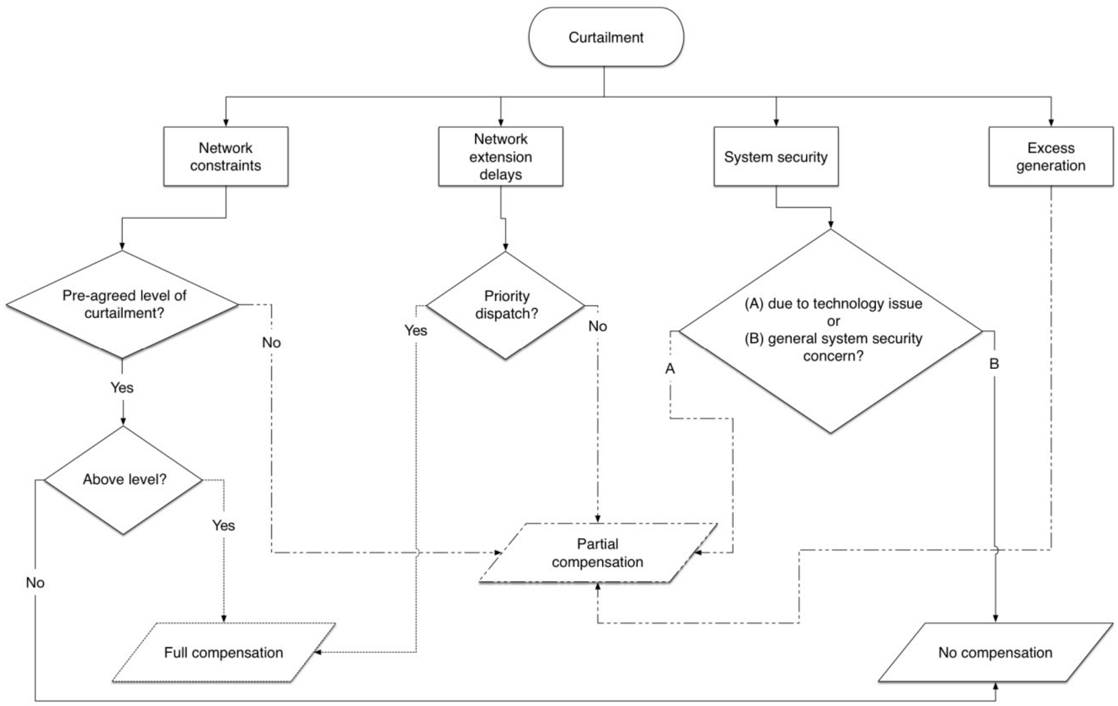

Figure 16: Curtailment instances[38] and their potential compensation.
Source: based on [15], [42]

Based in ***Figure 16***, it may be argued that depending on the reason for which the curtailment was required a different type of compensation could be suggested [15]. For instance, full compensation tends to be suggested when the regulatory framework in place provides explicit support, other than financial, to RES generators (e.g. surpassing regulated levels of curtailment, priority (dispatch) assignation, etc.).

Partial compensation may be suggested in instances when market forces, the nature of the technology (e.g. uncontrollability) or grid-related issues call for RES curtailment. In these cases, it is usually suggested that the subsidy is not paid to the DER Producer. Moreover, in case of market forces driving (voluntary) curtailment, the market price (zero in case of excess generation) or the subsidy could be given to the DER Producer. However, the incentive provided should not encourage DER Producers to keep bidding under zero or negative market prices. This is supported by the state aid guidelines for environmental protection and energy of EU (2014)[39] [43], which requires[40] MS to put in place

[38] Excluding strategic bidding.
[39] Art. 124 (c)
[40] as of January 1, 2016

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measures to "ensure that generators have no incentive to generate energy under negative prices".[41] Currently, efforts in this regard can already be seen. For instance, the German Energy Renewable Act (EEG) reduces the feed-in premium to zero if energy prices are negative for at least 6 consecutive hours. This entails no premium to be paid to DER Producers on blocks of hours (6 consecutive periods) in which negative energy prices are observed [44].[42]

No compensation in case of curtailment is suggested when the reason for the curtailment refers to a situation covered by the regulatory framework (e.g. regulatory curtailment level) or in case of a critical grid situation (e.g. an emergency).

According to [28], curtailment approaches tend to be cheaper than reinforcement costs. However, it was not clear if the reduced profit due to curtailment (energy and/or subsidy) could be level-out by the level of compensation provided by the curtailment scheme, especially when a market is implemented (since the compensation level will depend on the size, liquidity and competition of the market).

All in all, the scheme used to compensate RES curtailment will depend, in Europe, on policies at both European and national level and on the alignment between national regulatory frameworks and national energy targets.

In view of current developments, it seems that the EU supports partial compensation for grid-related curtailment initiated by network operators. In 2016, the EU [24] proposed that network operators requiring to curtail RES in-feed should compensate DER Producers.[43] This compensation "should at least be equal to the highest of additional operating costs caused by the curtailment or 90 % of the revenues (including subsidies) from the sale of electricity in the day-ahead market." The accepted text (2019) [25] amends the above provision by allowing to combine both elements.[44] In addition, to consider the net revenues from the sale of electricity at day-ahead, instead of a 90% cap.

2.9 Support schemes

Support schemes impact the compensation provided to RES owners in case of a grid-related curtailment, but also drives to a certain extent market decisions of RES owners. The latter is especially important when dealing with voluntary (economic)[45] curtailment. In addition, priority rules, when implemented, hinder the application of optimal solutions when dealing with network technical constraints. Therefore, this section provides a brief explanation of the support schemes and priority rules implemented today in the countries represented by the consortium.

---

[41] Note that art. 124 do not apply to installations with an installed capacity lower than 500 kW or demonstration projects (art. 125)

[42] This measure was introduced in EEG 2014 (§24) and then keep for EEG 2017 (§51).

[43] Article 12 paragraph 3 & 6.

[44] If by applying just one results in a unjustifiably low or high compensation.

[45] Market-related curtailment

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Currently, in Europe, energy from variable renewable generation (i.e., wind[46] and solar PV) enjoys financial support in the form of a subsidy. ***Figure 17*** shows the current support schemes and priority consideration for select countries.

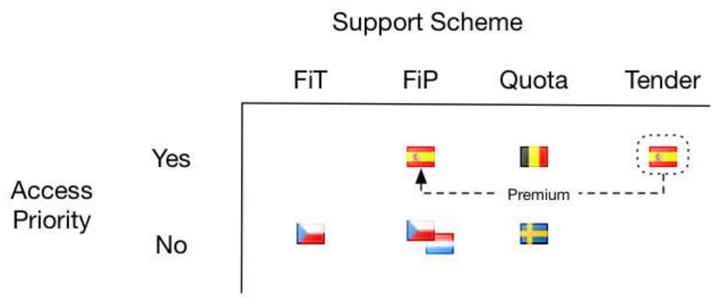

Figure 17: Support scheme and priority access for select MS.
Source: [29]

The implementation of these support schemes varies across MS. ***Table 4*** illustrates these differences for wind and solar PV.

		Support Scheme Characteristics		
		Type	Assignation	Subsidy
Countries	Belgium	Quota (Green Certificates)	**Brussels:** Solar PV -> 2,4-3 GC/MWh Wind -> 1,81 GC/MWh **Flanders:** Solar PV -> 1,3-1,4 MWh/GC Wind -> 1,6 kWh/GC **Wallonia:** GC = Eenp * (min(platfond; kCO2 * kECO))	**Minimum price** Brussels: 65 €/GC (obligation Elia) Flanders: 93 €/GC (inst. after 2013) Wallonia: 65 €/GC (obligation Elia) **Average GC price** Brussels: 95 € Flanders: 89 € Wallonia: not available
	Czech Republic	FiT		PV: 105-338 €/MWh Wind: 74-92 €/MWh
		FiP		PV: 60-517 €/MWh Wind: 42-77 €/MWh
	Netherlands	FiP		PV: 9-10,6 €ct/kWh Wind: 5,4-8,5 €ct/kWh
	Spain	FiP	Tender	Lowest accepted premium
	Sweden	Quota (Green Certificates)	1 GC/MWh	Average price: €12,1 (2017)

Table 4: Characteristics of support schemes for select MS.
Source:[29], Belgium: Elia, Brugel, VREG, SPW.

In **Belgium**, each region implements the quota scheme in a different manner. The support that is laid down depends on the energy source, generation technology, installed capacity and commissioning date. For example, in the Brussels region the scheme differentiates between PV capacities that are

[46] This document focus on Inland/onshore wind

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below/above 5 kWp, while in the Flanders and Wallonia[47] regions the subsidy is provided to PV units with a capacity above 10 kWp. This is highlighted by ***Table 5***.

		Quota support	
		Capacity	GC per MWh
Brussels	PV	< 5 kW	3
		> 5 kW	2,4
	Wind	< 1 MW	1,81
Flanders	PV	> 10 and ≤ 40 kW	1 per 1,4
		> 40 and ≤ 250 kW	1 per 1,3
		> 250 and ≤ 750 kW	1 per 1,3
	Wind	≤ 4 MW	1 per 1,6
Wallonia	PV	> 10 kW	GC = Eenp*Tcv Tcv = min(plafond; kCO2*kECO)
	Wind		

Table 5: Quota implementation across Belgian regions.
Source: [29], Brugel [46], VREG [47], SPW [48]

Note that for the Brussels region installations above 1MWp, there is a limit for GC (1 GC = 1 MWh). This limit does not apply to PV installations.[48] In Flanders, the amount of electricity to be generated per green certificate varies across technologies since the assignation is based on a technology-specific banding factor. The values shown for Flanders are valid for installations erected after August 8, 2018 [29]. The values for the formula applied in Wallonia, that is, the CO2 savings rate (kCO2) and the economic performance coefficient of the renewable energy technology (kECO), can be obtained from [48]. In Wallonia, currently there is a maximum of 2.5-3 CV per MWh (value depends on the date of the introduction of the plant).

In **Czech Republic**, the Feed-in Tariff (FiT) and the Feed-in Premium (FiP) are no longer used for new renewable installations [17].[49] The FiT stipulates the price at which the state purchase the energy produced by PV (put in operation before 31/12/2013) and Wind (put in operation before 31/12/2015) installations.[50] The FiP is paid on top of market prices to PV and Wind (with the same operation dates as above). Payments, in both schemes, for PV depend on the date of commissioning and installed capacity,[51] while payments for wind installations[52] depend only on date of commissioning [29]. Renewable producers may choose once a year their support scheme[53].

[47] Solar PV with a capacity equal or less than 10 kW commissioned between March 1, 2014 and June 30, 2018 can profit from the Qualiwatt support scheme [45]

[48] Art. 21 §4, Arrêté du 17 décembre 2015 [46]

[49] as of January 1, 2014.

[50] However, according to the Transitional Provision No. 1 Act No. 165/2012, renewable energy plants with a maximum capacity of 100 kW (except small hydro), that were put in operation before 31 December 2015 are eligible for FiT [29].

[51] Eligible installations up to 30 kW and installed on rooftops or façades.

[52] Up to 100 kW

[53] Act. 165/2012. Annual feed-in tariffs and premiums are determined by the Energy Regulatory Office. Current Price decisión No. 3/2018 (entered into force 2019).

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In **the Netherlands**, the FiP implemented presents certain peculiarities for wind and solar installations. For wind, the premium paid to wind installations is based on the speed of the windmill (m/s). Full load hours vary across projects based on the net P-50 values.[54] For solar PV, only installations equal or above 15 kWp with a maximum throughput value of 3*80A are eligible. In addition, these installations are subject to a limit of 950 full load hours per year [49].

In **Spain**, a specific remuneration regime was stablished by Royal Decrees 359/2017 and 650/2017 in which wind and solar PV renewable plants receive an amount considered to provide a reasonable rentability.[55] Costs and values are calculated based on theoretical standard installations. The premium tariff (specific remuneration regime) is allocated via a call for tenders (Order ETU/615/2017). Only new installations are eligible. The tender has a bidding procedure of one stage in a sealed bid format from which, bidders receive the price resulting from the lowest accepted discount rate (Art. 9.2., Order ETU/315/2017).

In **Sweden**, a GC is issued for every MWh regardless of the technology used for energy generation[56] [29].

2.10 Priority rules

The so-called "priority of dispatch" rule introduced in the EU legislation (under Directive 2009/28/EC) implies that RES-E can only be limited because of security reasons. This means that the network operators have to exhaust all available market and operational tools at their disposal before resorting to curtailments of electricity produced from variable RES units.

As shown in ***Figure 17***, only two countries[57] apply priority dispatch to RES installations. In all Belgian regions (Brussels, Flanders and Wallonia) grid operators are obliged to provide priority access to electricity generated from renewable energy sources in case of congestion.[58] In Spain, electricity from renewable energy sources is entitled with priority of access [29], [36], [50], [51].

According to [52], there are reasons in favour and against this rule. A positive side of this rule is that it helps to achieve targets concerning renewable energy. In addition, the use of this rule may incentivise more flexible operation of conventional power plants. In the negative side, this rule may cause inefficient dispatches of generation.

The focus of the rule changed with the "Proposal for a Regulation of the European Parliament and of the Council on the Internal Market for Electricity (recast)" [24]. Within the proposal it is mentioned that this rule should be kept for small renewables (< 500 kW)[59], leaving other (larger) RES units outside the protection of this rule. The approved text [25] preserves this proposition with minor modifications in this respect. For instance, the size of a small renewable power generating facility was lowered to 400 kW. Also, note that renewable power-generating facilities that when commissioned where subject

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[54] § 5.1, art.41 [49]

[55] Price regulation has been stopped [17].

[56] Chapter 3 § 2 Act No. 2011:1200

[57] Some modifications in the Netherlands are expected in the near future [29]

[58] Brussels (Art. 5 and 24bis, Ordonnance du 19 juillet 2001); Flanders (Art. IV.5.3.1 Technisch Reglement); Wallonia (Art. 13, 6° Décret du 12 avril 2001)

[59] also for high-efficiency cogeneration installations and demonstration projects for innovative technologies.

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to priority dispatch "shall continue to benefit from it" if no significant modifications such as new connection agreement or increase of generation capacity take place. The impacts from this change on RES integration efforts are still to be seen. However, some pre-conditions for the smooth integration of RES can already be listed. Among these pre-conditions are (1) provide a level-playing field for conventional and non-conventional power units across markets and grid levels, (2) ensure liquid intraday and balancing markets, (3) allow RES units to provide system services (i.e. via the balancing mechanism) and (4) promote as much as possible market mechanisms in order to support transparency of actions, specially concerning approaches for RES curtailment and compensation.

2.11 Curtailment in Europe

Grid-motivated curtailment of wind and solar PV, and its associated compensation are becoming increasingly important in many MS. According to CEER [30], between 2016 and 2017 at least 17 TWh coming from RES were curtailed. The compensation paid to DER Producers due to curtailment amounted approx.. 1.3 billion Euros.[60]

As shown in ***Figure 18***, out of the 20.5 TWh curtailed between 2013 and 2017, Germany represents almost 80%. In fact, just in 2017, Germany curtailed more wind and solar PV than the volumes curtailed in Ireland, Italy and Spain for the five year period combined. Also, both Germany and Italy display an upward trend in terms of curtailment volumes. In contrast, Spain shows a decreasing trend, while Ireland remains mostly flat.

[60] Volumes and compensation levels for a total sample of 10 MS: Belgium, Bulgaria, Germany, Ireland, Italy, Lithuania, Norway, Portugal, Romania and Spain.

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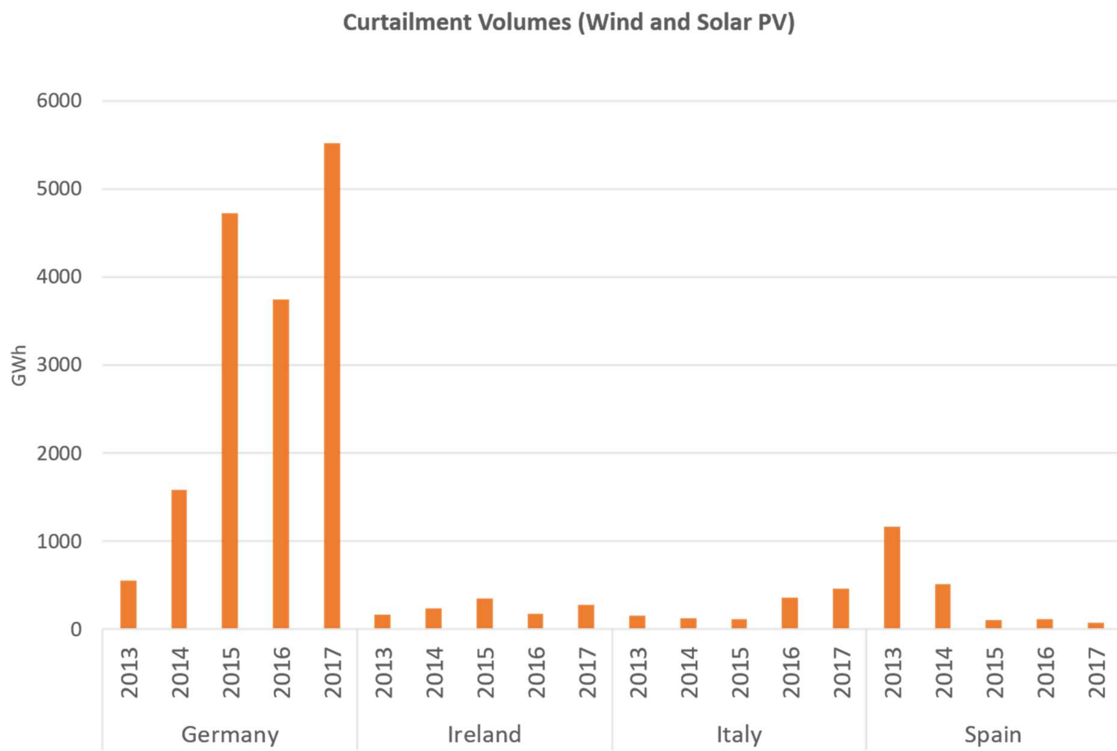

Figure 18: Curtailment volumes for Germany, Ireland, Italy and Spain
Source: [22], [30], [42], [53]–[55]

Available data on curtailment of renewable energy, mainly wind and solar PV, shows that the energy lost is still low (in comparison to the energy produced by wind and solar PV). From a sample of 10 MS[61], only four have shown a curtailment ratio[62] of at least 1% for the period 2013-2017 (***Figure 19***). Average curtailment ratios range from 0.1 % (Spain) to 5.3 % (Ireland). In respect to the energy that was lost due to the curtailment of renewable energy, mainly wind, the lost energy ratio[63] remains below 2% for each of the observed years.

In 2017, out of the four counties, Germany and Ireland show the largest curtailment ratio (3.8%), followed by Italy with 1.1%. Between 2013 and 2017, it can be observed that a common feature among these three countries is the upward trend in RES generation (GWh), which seems to coincide with increasing levels of curtailment ratios. Conversely, Spain shows a similar behaviour but in the opposite direction.

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[61] Belgium, Czech Republic, Denmark, Germany, Ireland, Spain, Italy, The Netherlands, Portugal and Sweden.
[62] Ratio representing the curtailed energy divided by the sum of the energy generated by wind and solar PV.
[63] Ratio representing the amount of curtailed energy divided by the total generation.

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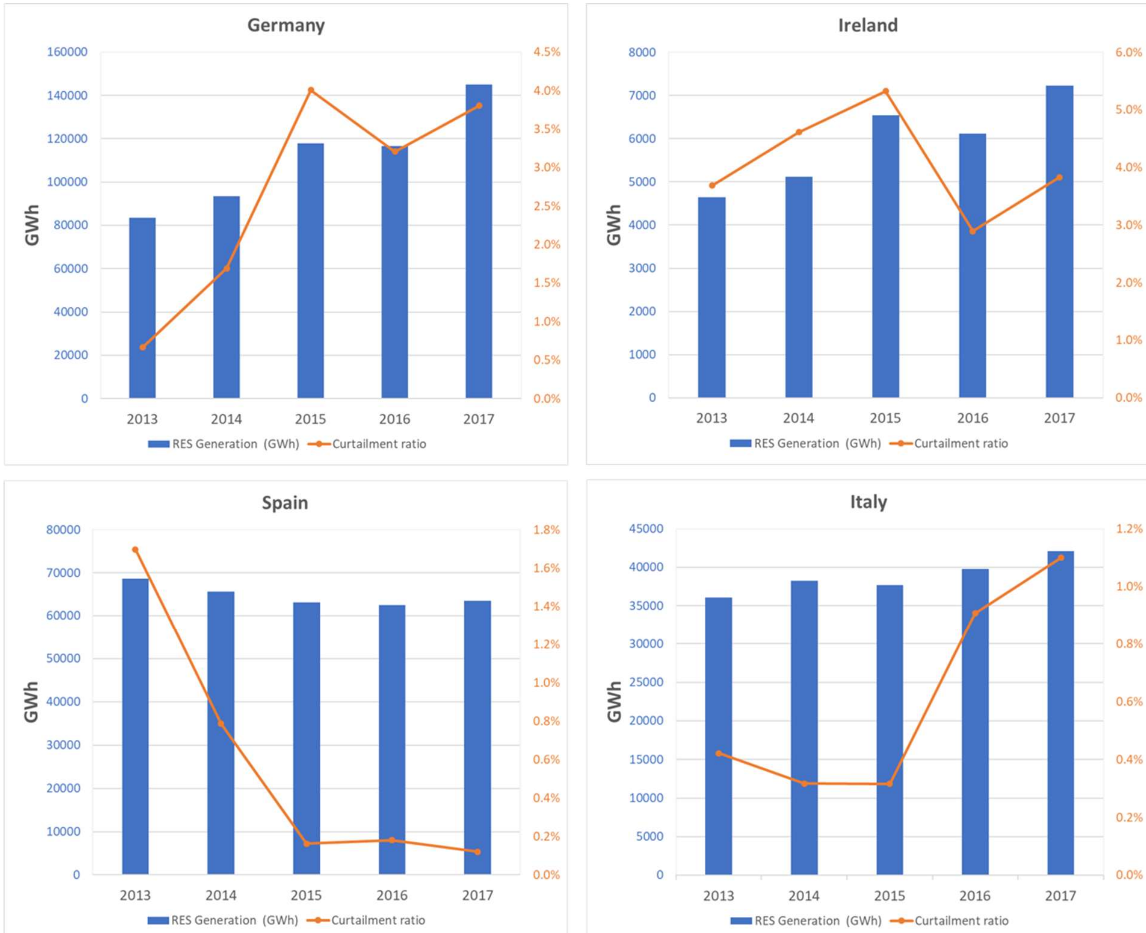

Figure 19: Figures on RES (wind and solar PV) generation and share of curtailed energy for select countries

Source: Eurostat[64], [22], [30], [53]–[55]

In the following, selected country examples are presented.

2.11.1 Denmark

According to [56], Energinet.dk, the Danish TSO has operated the system almost without curtailing wind generators. Curtailment of wind generators has happened only in two occasions: in 2008 and in 2010. Wind curtailment was about 200-300 MW for 6-8 hours (energy lost in the range of 1.2 – 2.4 GWh). Curtailments were ordered by TSO due to the outage of one of the strong interconnectors to the neighbouring countries. Note that almost all wind turbines (90 %) are connected at 60 kV (medium voltage) or lower. The Danish Energy Agency (DENA) argues that the introduction of negative prices (2009) in the NordPool Spot has helped to significantly reduce the need for grid related curtailment, but no numbers are available on the number of market related curtailments.

64 Eurostat database [nrg_ind_peh]. Last updated in 03-07-2019.

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2.11.2 Germany

Germany is one of the MS in which RES curtailment has increased in the period 2013-2017. According to [57], in 2015 RES curtailment has almost tripled (when compared with 2014). The amount paid as compensation for curtailment also increased significantly. Compensation payments totalled 315 million Euros representing more than 3.5 times the amount paid in 2014 (€83m) for the same concept. Moreover, the claims for compensation, resulted from the feed-in management measures[65], were estimated at 478 million Euros in 2015.

As in previous years, unused/spilled energy primary involved wind generators (87.3%), followed by Biomass (8%) and solar (4.7%). Note that Biomass replaced solar as the second leading technology affected by curtailment measures in 2015.

In 2017, 5,518 GWh were curtailed as a result of feed-in management measures. A new high on the amount of renewable energy curtailed. As in previous years, wind onshore accounted for the lion's share with 80%, followed by offshore wind with 15%. The total estimated claims for compensation rose to 610 million Euros. This represents a 64% increase in comparison to the 373 million Euros paid in 2016 [53].

2.11.3 Ireland

In Ireland, a distinction is made between curtailment and constraints. The former refers to system-wide issues for dispatch-down wind generation. The latter refers to local network issues that require wind generation to be limited. Curtailment in this case is not remunerated, while constraints are remunerated and subject to various rules.[66] The balance between constraints and curtailment varies from year to year (***Figure 20***). According to [55], in 2017, reasons for a higher level of RES curtailment (compared to 2016) are a significant increase of wind installed capacity (744 MW, which represents more than double the average annual wind connection level of 365 MW), small changes in demand and no changes in the interconnection capacity.

[65] Feed-in management measures refers to "curtailing feed-in from renewable energy and combined heat and power (CHP) installations at the network operator's request with compensation being paid" [53]
[66] According to [22] changes to the remuneration scheme are expected by 2018.

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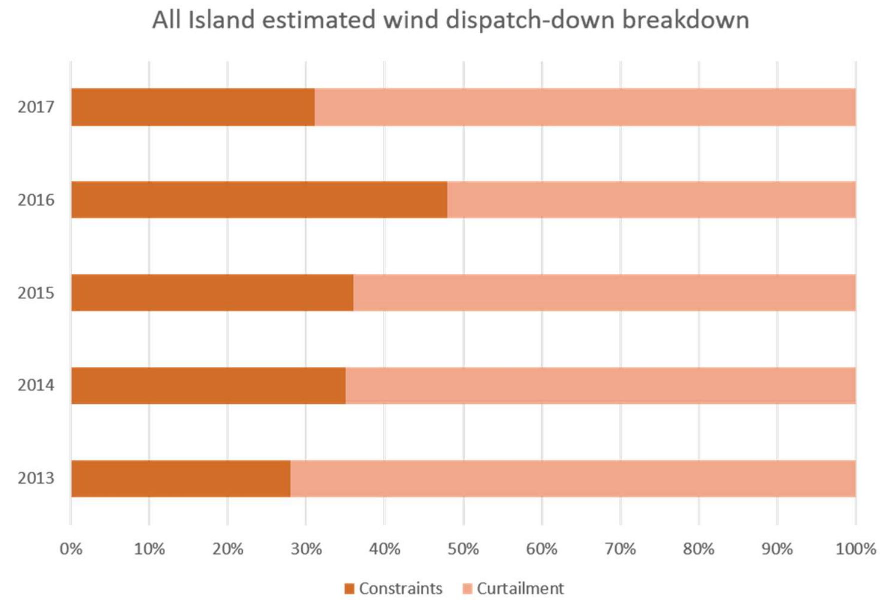

Figure 20: All Island estimated wind dispatch-down breakdown 2013-2017
Source: [55]

2.11.4 Italy

According to [22], the low levels of RES curtailment (mainly wind) may be due in part to the significant grid investments carried out in the past (previous to 2013). However, since 2016, RES curtailment (wind mainly at transmission level, while solar PV is more present at distribution level) have been on the rice, reaching 1.1% in 2017. In case of curtailment, affected wind energy producers that comply with the grid code (edition 2009) are fully compensated without limitation. Wind projects that do not comply with the grid code are not compensated for the first 80 hours of curtailment. Compensation payments are also on the rise. In 2017, curtailment costs reached 17 million Euros. This represents a 142% increase compared with 7 million Euros paid in 2016.

2.11.5 Portugal

In Portugal, RES curtailment is rare. Only recently, REN, the Portuguese system operator, ordered wind plants to dispatch-down on three occasions. Requests to dispatch-down were around 80-90 MW (90 MW in the first request and 80 MW for each of the two subsequent requests as shown in ***Figure 21***). The Portuguese legislation (FiT) compensates spilled energy from wind farms when losses exceed 50 h (at full capacity) [22].

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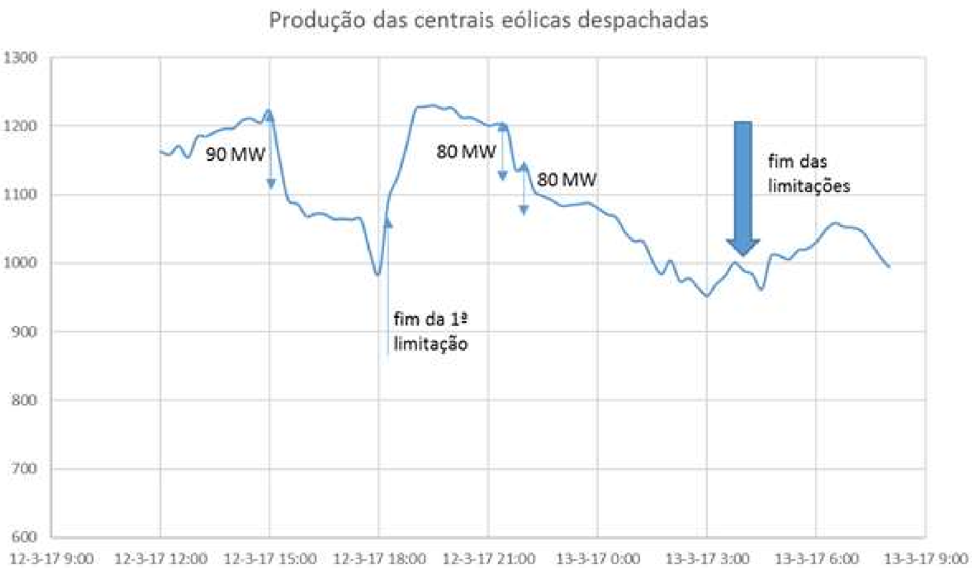

Figure 21: Dispatch down of wind farms in Portugal (2017)
Source: [58]

2.11.6 Spain

In 2013, technical restrictions of the PDBF and in real time required wind generators to reduce input for an amount of 1.166 GWh [22], [59]. In the first trimester of 2013 already 850 GWh of wind energy were curtailed. By the first quadrimester curtailed energy reached 984 GWh. Just in this period more wind energy was curtailed than in the previous five years[67]. The energy spilled in the first quadrimester was estimated at 85 million Euros.

Since 2016, all redispatch due to congestion management in the distribution or transmission grid is done via market mechanisms. By allowing participation of distributed generation in these mechanisms, system operators are rarely in need to curtail, in real time, renewable generation for security reasons. In these mechanisms, the downward bid price tends to be close to zero €/MWh and thus, the RES generator can keep most of the hourly market marginal price at which he/she sold the energy. This incentive allows for RES feed-in to be reduced through these mechanisms (congestion management or balancing market).

2.11.7 Sweden

In Sweden, RES curtailment due to technical constraints is rare. However, the requirement for RES owners to implement necessary grid reinforcements (in case their project needs it) may serve as an incentive to limit generation capacity. According to [22], a wind plant connected to a DSO has curtailed his output up to 3.3 MW (installed capacity 29.3 MW, in-feed limited to 26 MW) in order to avoid such (reinforcement) costs.

All in all, to the authors knowledge, RES curtailment volumes are rare in most MS. Apart from Germany, Ireland, Italy and Spain, no considerable amounts of curtailed energy from wind and solar PV were observed. Countries like Belgium and Portugal did show an increase on curtailed volumes in

[67] In the previous 5 years, no more than 700 GWh were curtailed from wind [59].

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2017 from 2016[68], 3.8 and 1.6 GWh, respectively [30]. However, these values are lower than 0.1% of the total energy generated by wind and solar PV in the respective countries. Other countries such as Czech Republic and The Netherlands reported that no RES volumes were curtailment between 2016 and 2017.

2.12 Prospections

Instances in which RES curtailment is used may increase in the coming years. This increase may be driven by the expected increase of RES capacity (mainly wind and solar) in Europe. ***Figure 22*** shows the expected evolution of wind and solar capacities for ten MS.

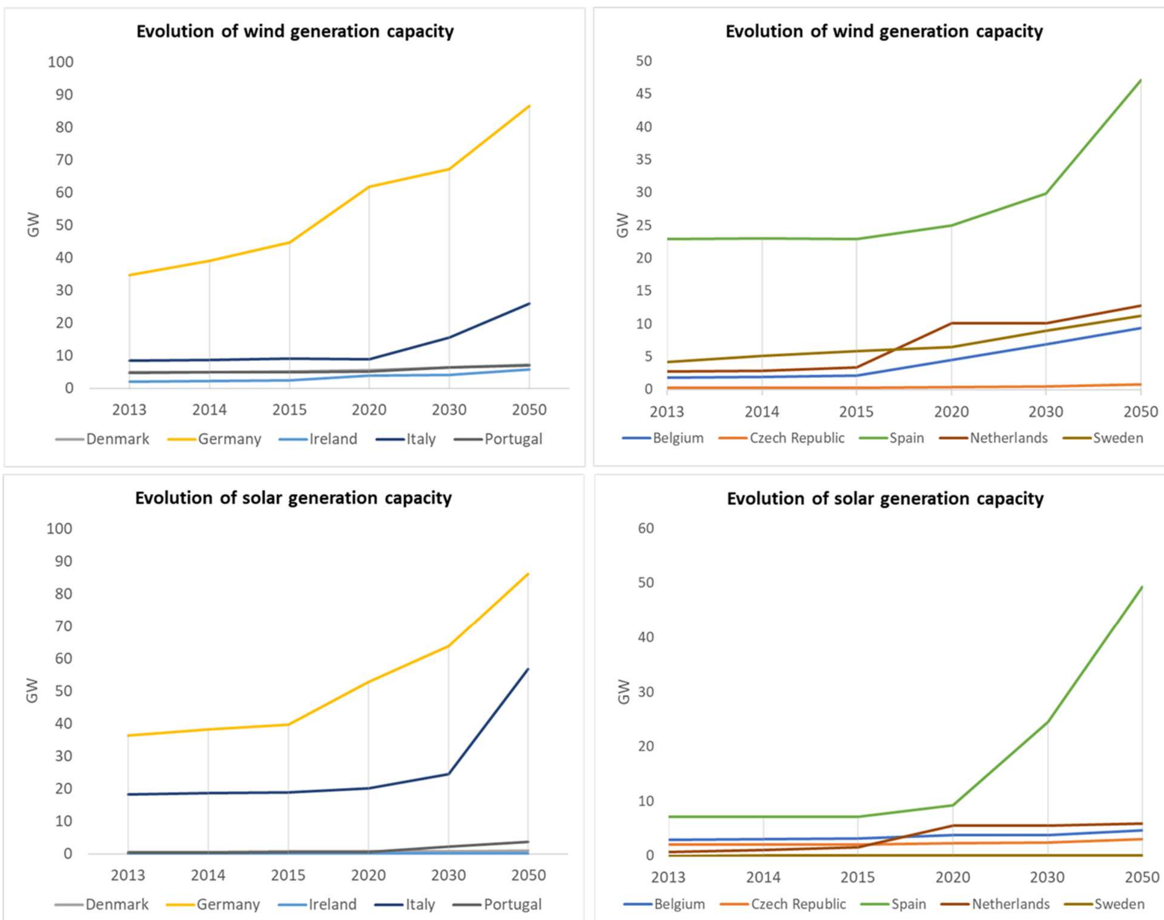

Figure 22: Evolution of wind and solar generation capacities for 10 select countries.
Source: Historical data: [42], [54], [55], [57], [59]–[61]. Data on future scenarios (2020, 2030, 2050): [62]

With the increase of wind and solar installed capacity, more variable renewable energy will be injected into the system. ***Figure 23*** illustrates the historical and expected contribution of energy generated from RES units to the total energy generated in select countries.

[68] Volumes for both countries were zero in 2016 [30].

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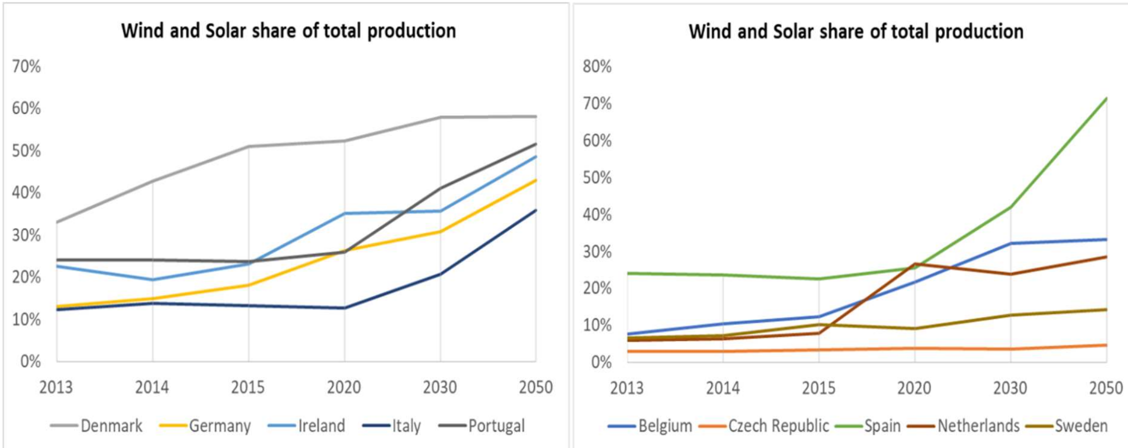

Figure 23: Evolution of wind and solar contribution to total production for 10 select countries.
Source: Historical data: [42], [54], [55], [57], [59]–[61]. Data on future scenarios (2020, 2030, 2050): [62]

Figure 23 shows that by 2020 most countries (7 out of 10) would be producing more than 20 % of the total energy injected to the grid from RES. Note that countries like Denmark, Ireland, Portugal and Spain passed the 20 % threshold a few years back.

Expectations are on the rise concerning RES curtailment. Take Spain for example, in 2015, the wind energy curtailed by REE, the Spanish system operator, both planned and real time, reached 103 GWh [63]. According to [54], REE has proposed a new mechanism to minimise undesired production losses. However, even with this mechanism, for 2020, REE expects to curtail 3.6% of wind and solar generation (approx. 2.6 TWh). These figures highlight the potential for flexibility options given current market and operational mechanisms to manage large amounts of variable renewable generation.

Market and operational rules concerning RES curtailment will be fundamental in the integration of renewable sources. However, they alone may not be enough. According to [64], current rules of RES curtailment may increase market prices. Authors of the CPI report argue that the "6-hour rule"[69] could increase wind bid prices by 17 % in 2020 and more in future years, unless, authors continue, "other flexibility measures are taken." The analysis provided by the authors show that in this scenario investors would face increased risk and uncertainty. A higher risk driven by voluntary (economic) curtailment will increase prices and lower production. Therefore, authors of the report suggest to explore appropriate policies to lessen curtailment risk and champion the cause in which the negative impact of curtailment is mitigated by sound market and operational rules as well as technological developments.

Technological developments such as Demand Response (DR) show a promising future. According to [65], DR may contribute to reduce RES curtailment and the use of fossil fuels. Especially, at distribution system level. For all scenarios studied in [65], RES curtailment was modest. However, the authors point out that in scenarios with high variable RES, curtailment may increase to considerable values, especially in countries where the resource shows a high concentration level, limited flexibility options and a low level of connectivity with neighbouring countries.

[69] In short, this rule stipulates that if during a period of consecutive hours (at least 6 hours) wholesale energy prices are negative, the subsidy (premium) would be set to zero for those hours.

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The study in [65] also suggests that capping RES feed-in may bring limited benefits or even increased costs. In this case, the benefits of reduced distribution expansion may be drastically reduced (more than half) or even offset by the value of lost energy. This serves as a reminder that, although RES curtailment is a viable option for the integration of variable renewable energy sources, its use must be balanced with other flexibility options.

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3 Relevant Roles/Actors for RES Curtailment Mitigation

A key aspect of business case design is to determine which adapted or new functionalities from which roles/actors are needed. In general, roles describe a high-level responsibility (as a group of related functionalities) whereas an actor described a physical stakeholder (company), system or equipment. In general, an actor can have multiple roles. For some roles, there is no doubt to which actor it is assigned, whereas for other roles, the mapping on actors can be determined by country specific legislation and regulation, or it may evolve as the role is being adapted/extended to fit with a changing reality. In this document, we will use the terms roles/actors in an interchangeable manner, though this should be interpreted as being roles, and when an actor name (like DSO[70]) is used instead, what is meant is 'all roles that likely are strictly tied to that actor'.

Our approach:

Step 1: identify prime beneficiaries (roles/actors) for the business use cases. I.e. those roles/actors that could/should see a direct value in mitigating RES curtailment. Describe in which way RES curtailment mitigation increases their revenues or reduces their costs, and describe specific functionalities and challenges in relation to the business use case.

Step 2: identify supportive roles/actors that are needed to implement the business use cases, i.e. to provide the direct value and benefit to the prime beneficiaries. Describe the functionalities and challenges related to these roles/actors for the business use case.

3.1 Prime Beneficiaries / Roles

3.1.1 DER Producer

Brief description of role/actor in relation to FHP Business Case
Producing/generating energy from an intermittent renewable primary source, e.g. wind power or photovoltaics. Injecting energy (except portion that is self-consumed) into the (distribution) grid.
Why do they have a direct interest in the FHP Business Case
DER Producers strive to operate their assets at maximum efficiency, maximizing the economic return of the investment and the operation. This implies full utilization of renewable energy sources, unconstrained by conditions in the (distribution) grid and unconstrained by market situations. They want to sell all the possibly produced energy to the day-ahead and intraday markets, thereby maximising the economic efficiency of their investment. Therefore RES curtailment means that they **lose money** directly (e.g., less energy sold, less subsidies) or indirectly (because their

[70] in reality a DSO has many roles that are evolving: see [1]

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investment is not operated at its max capacity). [71]
What specific (new/adapted) functionality is required for the FHP Business Case
Accurate and timely forecasts (day-ahead and intra-day) are important so that a consumption rescheduling action can be done to avoid or mitigate the curtailment. BRPs can do better planning and take actions to align consumption accordingly when bidding to markets or engaging in bilateral OTC trading. And DSOs can use the same information to perform a grid safety analyses and work with flexibility providers to adapt consumption at the right place and time.
Challenges/Barriers
The cost of paying for flexibility activation must be sufficiently low … lower than the money lost because of the curtailment that otherwise would take place. Therefore, it probably is important to – next to the economic cost – also take into account environmental and societal costs associated with RES curtailment. They may be partly compensated for the curtailment already (by the party causing the curtailment in case of involuntary grid related curtailment for instance): the more they are compensated, the less there is a need for them to use flex activations as an alternative to RES curtailment.
Relevant Business Use Cases:
▪ localRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess local RES (too much injection) *(for distribution grid connected RES)* ▪ systemRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)* ▪ balancingServices: Intra-ISP flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*

3.1.2 DSO

Brief description of role/actor in relation to FHP Business Case
Operating the distribution grid in a safe and efficient manner i.e. avoiding congestions and voltage problems (security and quality of the electricity supply), and minimizing/postponing avoidable grid reinforcements, while at the same time supporting increase of RES connections.
Why do they have a direct interest in the FHP Business Case
When they invoke grid related curtailment, they **lose money** because they must (or may must in future) pay (partial?) compensation.

[71] Actually, also consumers and society as a whole lose money, as curtailment of RES means more fuel based generation which has an effect on the environment, and on wholesale electricity prices.

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The must support max amount of RES with minimal grid reinforcements[72]. Current practice is to agree certain amount of peak hour curtailment; while this is supporting a growing amount of baseload RES, it does put a barrier on RES investments, and does not use the full potential of the RES investment which is seen as an energy in-efficiency matter and a lost opportunity to reduce fuel based generation to the benefit of the environment and consumer energy cost. The Winter Package [23] therefore states that "*Member States should put in place appropriate measures such as national network codes and market rules, and incentivize distribution system operators through network tariffs which do not create obstacles to flexibility or to the improvement of energy efficiency in the grid.*"
What specific (new/adapted) functionality is required for the FHP Business Case
Active System Management[73]: increase observability, actively engage with other stakeholder to forecast problems and take proactive actions.
Challenges/Barriers
Regulatory barriers: DSOs are generally not allowed to invest in or operate generation devices, including energy storages. Therefore there is a need for active engagement with other stakeholders like DCMs to procure flexibility services. If no compensation must be paid for grid-related RES curtailment, or if large portion of it is non-transparent (i.e. done by the invertors automatically), there is no need/incentive to acquire flexibility services to mitigate such RES curtailment. Lack of (adoption of) standardisation of information exchanges and interoperability to engage with the flexibility stakeholders (DCMs).
Relevant Business Use Cases:
▪ localRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess local RES (too much injection) *(for distribution grid connected RES)*

3.2 Supportive Actors

3.2.1 DCM (Dynamic Coalition Manager)

Brief description of role/actor in relation to the FHP Business Case
Aggregating, using and trading flexibility on behalf of flexibility providers (in FHP, the Heat Providers) in support of energy system stakeholders that need flexibility to manage and improve their business and/or operation.

[72] The proposals gathered in the Winter Package launched by the European Commission in November 2016, encourages DSOs to cost-efficiently integrate renewable energy sources, and new loads such as heat pumps and electric vehicles. DSOs should be enabled and incentivized to use services from DERs to operate their networks efficiently and to avoid costly network expansions.

[73] EURELECTRIC's position paper: Active Distribution System Management, 2013.

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The Dynamic Coalition Manager is a specialization/extension of the traditional Aggregator. Such a traditional Aggregator typically only aggregates and trades flexibility (= upwards/downwards regulation capacity) for system level services like providing Intra-Day balancing capacity for BRPs or ancillary services capacity for TSOs. A (pure) Aggregator is merely aggregating and packaging flexibility into flexibility products that are offered to other stakeholders, without deciding on any activations himself. Basically, he is only interested in the upward/downward regulation capacity, not in consumption profiles.

The DCM on the contrary can have its own objective for which he uses and decides on activations of flexibility himself. This can be as a (neighbourhood) cooperative that does a collective optimization, or it can be a separate ESCO that operates on behalf of such a neighbourhood cooperative. A typical example could be a self-consumption or peak shaving optimization where by using the combined flexibility of a cluster of flexibility providers, a better result can be achieved than if each flexibility provider would do its own optimization himself (if they even would have the knowledge and capabilities to do so) without coordinating with the others. Typically, this type of optimization focuses on local services, and for being able to do the optimization, not only upward/downward regulation capacity but also consumption profiles are needed. Any flexibility that is not needed/used for the local service (i.e., the flexibility that remains after part of it has been used to adapt consumption profiles for the local service) can be used for offering system level services i.e., offered to a traditional aggregators if this is a separate ESCO (there can be competition between aggregators for acquiring this flexibility), or offered to BRP/TSO if the DCM/Aggregator roles are combined in a single actor (the latter is what we assume for the project).

Why do we need this role/actor for the FHP Business Case

The DCM is the actor that bridges between the prime beneficiaries (DSO, BRP, DER Producer) of the business case that need consumption flexibility to mitigate RES curtailment, and Heat Providers that offer such consumption flexibility.

This is fully aligned with the *Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity*[74], that regulatory frameworks should be designed to encourage aggregators to participate in the retail market by permitting them to enter retail markets without consent from the other market participants. Specifically, this states that member states should ensure access to and promote participation of demand response through independent aggregators in all organized markets, including ancillary services and capacity markets.

Why do they have an interest in supporting the FHP Business Case

For flexibility service providers, it is crucial for the viability of their business that they are able to provide as many as possible flexibility based services to as many as possible stakeholders. The broader the range of application fields, the more likely that their business can be made profitable in the smart grid context.

For the RES curtailment mitigation business case, we propose three business use cases / services they can offer to their services portfolio, enabling them to grow their business. These new services constitute new revenue channels (multiple business models can be explored for these).

[74] https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v7_864.pdf

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What specific (new/advanced) functionality is required for the FHP Business Case
Optionally: (offering support to Heat Providers to) forecast baseline consumption and identify and quantify flexibility of Heat Providers. Aggregate flexibility from Heat Providers *(we assume Heat Providers are capable of assessing their own flexibility; if not this is extended functionality for the DCM i.e., offering support in identifying and quantifying flexibility)*. *Optionally: value-adding (for Heat Providers) cluster level optimization e.g., self-consumption (avoiding buying expensive energy or paying injection penalties).* Interactions and negotiations with actors that need flexibility for the RES curtailment mitigation business case (DSO and BRP) on behalf of the Heat Providers (flex offers, flew requests and flex orders).
Challenges/Barriers
Sufficient value of flexibility i.e., incentive schemes must be sufficiently attractive. The revenue streams associated with the proposed business use cases are capped by the avoided cost/losses of the prime beneficiaries (possibly augmented with a value factor related to contribution to reaching sustainability targets) which must be distributed across all actors/roles that are needed to provide the functionality. Freedom of Heat Providers versus agreement to honour agreed flexibility activations. The business models must be based on the freedom of Heat Provider to decide if, when and how much flexibility they are willing to offer. But if flexibility is offered and ordered in response for an incentive, this order should be honoured – in good faith – by the Heat Provider? Cost effective monitoring (i.e., do Heat Providers do what they were asked and committed to do) and settlements of flexibility activations by Heat Providers (frequent small activations). Gaming by Heat Providers must be prevented. Baselines (flexibility activation = change compared to baseline) may be hard to establish. Need simple and robust business models for settlement. Standardisation of information exchanges and interoperability to interact with divers Heat Providers and DSO/BRPs. Optimal Mapping of DCM role on separate ESCO or aggregator or BRP or retailer (see also JRC report *Demand Response status in EU Member States*[75]). E.g. there is a blurry border between the value proposition of retailers or DSOs in Demand Response programmes (e.g., ToU tariffs from Retailers/BRPs try to steer consumption patterns through 'static' contracts) and the activities of a pure aggregator or DCM that try to steer consumption patterns or provide flexibility capacity in a more dynamic manner. Aspects like maximizing competition versus business viability of service providers that support the system need to be considered.
Relevant Business Use Cases:

[75] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101191/ldna27998enn.pdf

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- localRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess local RES (too much injection) *(for distribution grid connected RES)*
- systemRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*
- balancingServices: Intra-ISP flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*

3.2.2 BRP

Brief description of role/actor in relation to the FHP Business Case
Maintaining and offering a portfolio of generation and consumption to system level markets (Day-Ahead and Intra-Day) resulting in an optimized nomination (i.e. how much energy it can produce/sell and consume/buy at which cost and when). As such, representing the DER Producers and Retailers (implicitly: Heat Providers) in the process of energy sale/purchase.
Why do we need this role/actor for the FHP Business Case
The BRP is the one who decides on system RES curtailment either DA/ID (systemRESCurtailmentMitigation business use case) or intra-ISP (balancingServices business use case). He is involved in any decision that involves increasing flexible consumption (in his consumption portfolio) as an alternative to reducing RES generation (in his generation portfolio).
Why do they have an interest in supporting the FHP Business Case
Curtailment of RES because of economic/market/system balance reasons is quite common already, and will become even more important as the amount of RES in the generation mix increases. While at first sight it is counter-intuitive to curtail zero marginal cost RES as opposed to fuel-based generators, this is caused by priority dispatch regulation and the ease with which invertor coupled RES can be curtailed, compared to traditional synchronous generators. Increasing consumption as an alternative from RES curtailment can be an attractive alternative for BRPs to optimize and improve their business operation. SystemRESCurtailmentMitigation business use case: if excess generation is offered to the DA/ID market, selling more consumption from own contracted portfolio instead of selling less generation from own contracted portfolio (resulting in curtailment of DER Producer), improves the BRP business. Especially if this correction can be done by a bilateral OTC trade between the BRP and the DER Producer. BalancingServices business use case: if an intra-ISP signal forecasts excess generation in the current ISP, the BRP could increase consumption from his own contracted portfolio, improving his business by selling more consumption (instead of selling less generation), and additionally earn incentives for his balance correcting activity instead of being potentially penalized for being co-responsible for the imbalance.

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Indirectly they also benefit from the localRESCurtailmentMitigation business use case: by being informed of scheduled local flex activations (e.g. changes in consumption plans) the BRP is better informed about what will happen and can improve his bids to the market, and this way mitigate the risk of being not in balance later (e.g. he can correct his own baseline consumption forecasts with precise knowledge instead of imprecise forecasts of flex activations).
What specific (new/advanced) functionality is required for our FHP Business case
Forecast consumption of their portfolio (which is offered through retailers). Interact with DCMs (as a proxy to Heat Providers in their portfolio that offer flexibility) and DER Producers.
Challenges/Barriers
BRPs have a long-lasting expertise in forecasting baseline consumption profiles. But a challenge arises to forecast flex activations and their impact on the baseline. Our solutions help them by providing precise information of scheduled flex activations, so they no longer must try to forecast these themselves. Accurate and timely information (esp. for the balancingServices business use case). Standardization of information exchanges and interoperability to interact with DCMs (or aggregators as a proxy to DCMs) and DER Producers. Value of our solution (flex activations, that come with a cost as incentives must be paid and other actors must be paid) versus cost of curtailment versus benefit of over-contracting (deliberate purchase/sale of more/less energy than forecasted to the end of limiting the financial risk of the imbalance cost, or to speculate on the imbalance direction)
Relevant Business Use Cases:
▪ systemRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)* ▪ balancingServices: Intra-ISP flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*

3.2.3 Heat Provider

Brief description of role/actor in relation to the FHP Business Case
Heat Providers are consumers that buy electricity from Retailers, and that next to uncontrollable loads, also have flexible Power-to-Heat loads (possibly more than one). This means their consumption profile can be subdivided in an uncontrollable part, and a part that can be controlled – hence is flexible – within certain boundaries. With their P2H devices, they offer/sell heat to one or multiple Heat Users (the ones that have the heat demand). Heat Providers are represented by a single connection point: both physically (one – metered – connection point to the distribution grid), and virtually (they – i.e., all associated Heat Users – are contracted to the same BRP/Balancing Group).

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Optionally, Heat Providers may have their own local RES (e.g., PV on a building): in that case, the Heat Provider's consumption profile/schedule is the net effect of its consumption and generation profiles (e.g., negative consumption means that there is more being generated than consumed).
Why do we need this role/actor for the FHP Business Case
The Heat Provider provides the consumption flexibility that is required to steer consumption in a way that RES curtailment can be avoided or mitigated. Based on incentives or control signals from the DCM, they can change their consumption plan/schedule.
Why do they have an interest in supporting the FHP Business Case
Providing flexibility constitutes a new source of monetary income for Heat Providers. Whereas Energy Efficiency measures reduce their energy cost, which potential may be small in well-insulated buildings, offering flexibility for local and system level services flexibility services is a means to earn incentives (or rebates). Individual Heat Providers are likely to be too small to directly trade power/energy/flexibility (through markets or other means), and currently the complexity to do so might be daunting. DCM/Aggregators can act as intermediaries to enable and facilitate such access, as proposed in the *Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity.* Besides facilitating the valorisation of flexibility, Heat Providers may benefit from additional services from DCMs, like consumption forecasting, flexibility modelling, and consumption optimisation. For the latter, the DCM may leverage the benefits of managing a larger pool of flexibility, i.e. clustering multiple Heat Providers, with consequently more optimisation potential and options. Besides, adjoining services like heath monitoring of HVAC systems may be done by detecting deviations from normal or modelled behaviour.
What specific (new/advanced) functionality is required for our FHP Business case
Modelling of dynamic thermal behaviour of heat demand to forecast electric consumption profile, to determine optimal electric consumption profile in relation to specific objectives (e.g., minimal cost), and to determine flexibility (e.g., as alternative profiles, operating boundaries, flex model): all of this with respect for comfort boundaries set by Heat Users, and operating constraints of the P2H devices. Replicability: expert-free grey-box model creation and tuning trough data-driven machine learning.
Challenges/Barriers
Limited economic value of flexibility (too low incentives) and non-standardised practices and processes. Maximum flexibility must be harvested – addressing multiple business cases and selecting at any instance in time the most profitable one - while not violating Heat User settings and P2H device constraints. Non-standardised practices and processes: need for standardization of information exchanges and interoperability to interact with DCMs, Heat Users and P2H devices.

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Lack of flexibility of P2H devices (like heat pumps) that are designed for max efficiency, rather than for offering flexibility services: need a grid flexible heat pump; direct control; standard interfacing. Freedom of Heat Providers versus commitment to honour agreed flexibility activations. The business models must be based on the freedom of Heat Provider to decide if, when and how much flexibility he is prepared to offer. But if flexibility is offered and ordered in response for an incentive, this order should be honoured – in good faith – by the Heat Provider?
Relevant Business Use Cases:
▪ localRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess local RES (too much injection) *(for distribution grid connected RES)* ▪ systemRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)* ▪ balancingServices: Intra-ISP flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*

3.2.4 Heat User

Brief description of role/actor in relation to the FHP Business Case
Needing/paying for heat from the P2H device(s) managed by the Heat Provider, and deciding on for instance setpoint temperatures and expressing willingness to provide flexibility (i.e. allowing deviations with respect to setpoints in return for an incentive), unless if the Heat Provider is authorized to decide this on his behalf as long as contractual agreements are not violated. This role can coincide with the Heat Provider (e.g., in case of a single-family dwelling).
Why do we need this role/actor for the FHP Business Case
Deciding on for instance setpoint temperatures and expressing willingness to provide flexibility, which is information the Heat Provider needs for the determination of baseline consumption profiles, optimal consumption profiles with respect to a specific objective, and available flexibility.
Why do they have an interest in supporting the FHP Business Case
Paying less for the same of better comfort, where all complexity and decision taking is delegated to the Heat Provider? Even though for a single Heat User the financial benefit of offering flexibility may be small, they likely are (increasingly more) sensitive to social reconnaissance, and nowadays, environmental awareness is a highly-appreciated indicator. Therefore, participating in and supporting initiatives that reduce RES curtailment, increase the amount of RES that can be locally integrated, and increase the amount of consumption coverage by such local RES is likely to be seen as an engaging factor.
What specific (new/advanced) functionality is required for our FHP Business case
Specifying willingness to offer flexibility.

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Challenges/Barriers
It is hard to define a good way to specific 'willingness to offer flexibility'. The intuitive approach to, specify this as a delta temperature (in reference to a setpoint temperature), might not work well. First of all because comfort is partly a subjective feeling, secondly because temperature may be affected by external non-controllable factors, causing temperature deviations outside the agreed comfort band, even if no flexibility was activated. The financial incentives may be (too) small to attract a lot of interest. Social reconnaissance or social gaming (comparing with peers) may be a more influential factor to persuade Heat Users to provide flexibility.
Relevant Business Use Cases:
▪ localRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess local RES (too much injection) *(for distribution grid connected RES)* ▪ systemRESCurtailmentMitigation: DA/ID flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)* ▪ balancingServices: Intra-ISP flex consumption planning/scheduling adaptations to coincide with forecasted excess system-wide RES (generation/consumption mismatch) *(for all RES)*

3.3 Other supportive/affected roles

3.3.1 TSO

The key (new) functionality that is expected for our business case, in particular for the balancingServices business use case, is the intra-ISP forecasting of the likely imbalance at the end of the ISP, and the informing of the BRPs about this early on in the ISP.

Based on that, if there is a surplus of generation, BRPs can decide to increase consumption instead of curtailing RES.

As for FHP the focus is on the distribution grid, we consider the TSO grid to be a copper plate. Specifically, for the systemRESCurtailmentMitigation business use case, this means that we are only concerned about the distribution grid status (i.e. what is the allowed flex capacity at the distribution grid that can be used for increasing consumption to absorb the excess RES).

3.3.2 Retailer

The retailer has the energy contracts with the Heat Providers. In this project, we assume this role/actor to coincide with the BRP.

3.3.3 Market Operators

System level Market Operators match the BRP **energy bids** (generation and consumption) in an optimal and grid/system secure manner to ensure **system balance**, resulting in nominations for BRPs.

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This matching and optimisation process may result in prices that result in system RES curtailment (i.e., if prices are too low or negative, DER Producers may decide to not produce/sell/inject energy).

In future, also **flexibility markets** could appear, where flexibility is traded between DCMs/Aggregators offering flexibility, and BRPs (**energy bids**) or TSOs (**energy capacity bids**) buying flexibility.

Besides, there could be **local flexibility markets**, that match **power and flexibility bids** to ensure **grid secure operation** (i.e. not causing local grid problems). These can be an alternative for bilateral engagements that use for instance an iterative dual decomposition[76] approach to find an optimal matching.

3.3.4 Government

Government sets the rules and regulation, e.g., related to subsidies/green certificates, or on what roles/actors are allowed to do, on cost structures (e.g., related to environment aspect) etc., and thereby their decisions can make or break business cases.

[76] Dual decomposition is a distributed control algorithm. Every agent represents a device and receives an price profile for a given horizon. In return it provides the power consumption over this horizon. A central unit collects these power profiles and checks if common constraints are met. If this is the case, those profiles are executed. Otherwise, prices are adapted. This is iterated until an agreement is reached (the implementation is patented: Power supply network control system and method, [PA-100100267]).

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4 Technological opportunities and functionalities

In FHP, we focus on business use cases that mitigate the forecasted curtailment of RES using distribution grid connected Power-to-Heat resources. P2H resources typically have flexibility that can be used to alter their consumption pattern without a relevant or even noticeable impact on their prime functionality (providing heat and comfort). If there is excessive RES that would normally lead to a grid related or market based curtailment decision, such P2H flex activations can be an alternative to the curtailment. By shifting consumption to coincide with these moments of excess generation, curtailment can be mitigated.

In FHP, we consider two types of P2H technologies: dynamic coalitions (clusters) of heat pumps in buildings on the one hand, and the Ecovat system on the other hand. Thermal storage in buildings heated by heat-pumps provides small and short-term P2H flexibility: e.g. buildings can be pre-heated and this way store this heat for several hours. In general, a certain amount of heat can be delivered to a building a bit earlier/later without any noticeable effect on the temperature or comfort. So this way, groups of buildings provide a very distributed (i.e. potentially many connection points in a particular distribution grid) and valuable source of flexibility for our purpose : local problems can be solved locally. The Ecovat system on the other hand is a more central (i.e. single connection point in a particular distribution grid) and large P2H system, designed for – but not restricted to - storing heat over seasons. It not only has a large energy storage capacity, but also a potentially large power capacity to absorb large excess RES peaks, only limited by technical/economic limitations regarding its connection capacity.

4.1 Dynamic Coalition of Heatpumps

P2H systems associated with buildings are mainly used for heating/cooling and for domestic hot water production. A typical P2H system configuration associated to a building that will be studied in the frame of the FHP project is composed by:

- A heat pump that consumes electrical energy, E_{HP}, and produces thermal energy, $E_{T.}$ This heat pump could use as primary energy source the energy available in the external air (aerothermal heat pump) or in the ground (geothermal heat pump). In this brief overview description we assume that the COP of the pump can be considered constant, and therefore E_{HP} and E_T are linearly dependent.
- The thermal energy produced by the heat pump heats a water tank that acts as an energy buffer, so that the control system of the heat pump maintains the temperature of the water tank at an average temperature T_T. This kind of reservoirs are originally installed to decouple the heat pump duty cycle from the tank demand, so that up to a certain point, the heat pump sizing can be reduced and its working rate can be adapted in order to maximize the energy efficiency of the pump.
- The HVAC system in the building consumes some of the thermal energy stored in the tank, E_B, to maintain the building spaces at a temperature T_S. In this brief overview description we assume that T_S is the same in all the spaces and we do not take into account the energy spending effect of intermediate elements that could be used to distribute the thermal energy in the water such as AHU, fan-coils, radiators…

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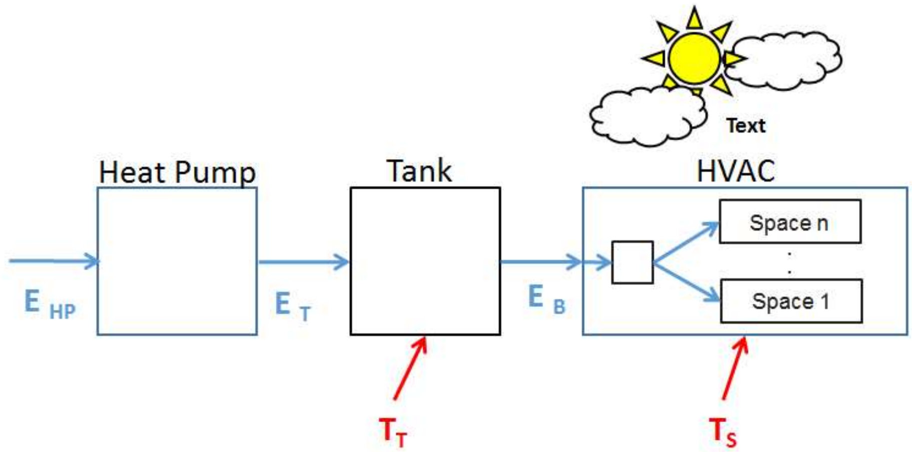

Figure 24: Schematic overview of a building P2H system.

In a non-flexible scenario, as a result of a business as usual operation strategy, the energy needed to cover building needs depends mainly on external temperature, as shown in the following figure for a typical office building. This energy profile represents the baseline energy consumption of the P2H system, and represents the reference curve from which flexibility is calculated when the building varies its intended consumption due to a flexibility request.

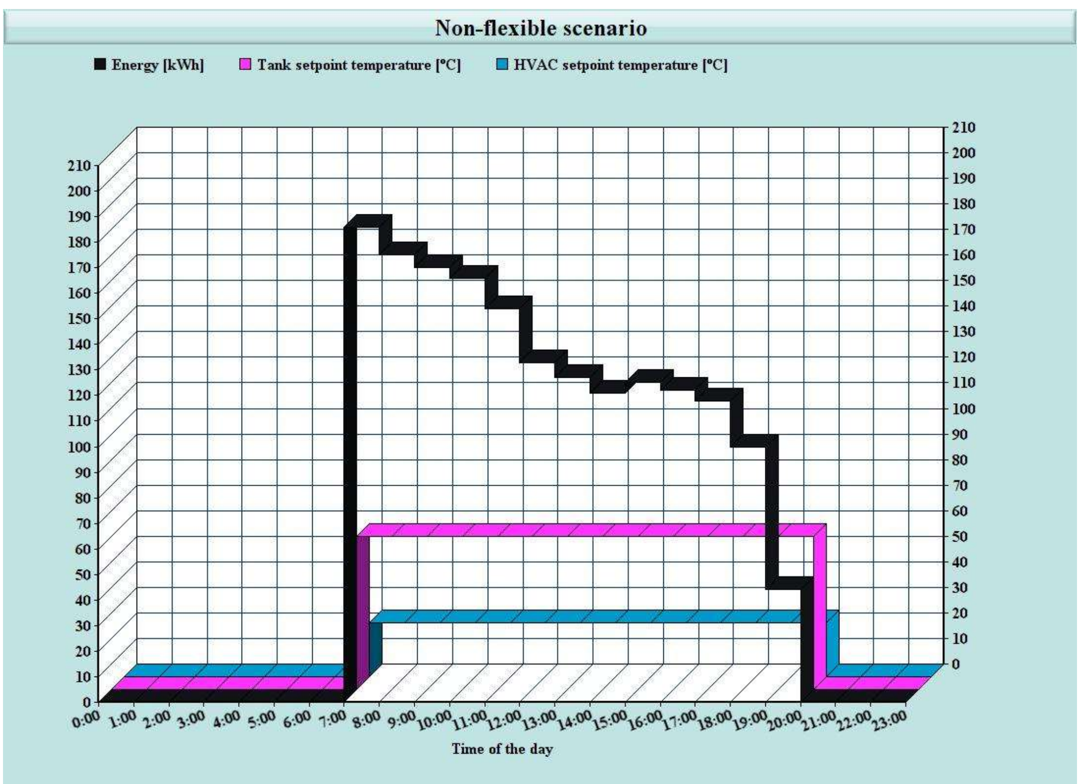

Figure 25: Non-flexible heating scenario.

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An hour before the working timetable begins, at 7:00 AM, the heat pump and the HVAC are turned on, and therefore the setpoints of the tank and the HVAC are enabled until the office timetable ends at 8:00 PM.

The heat pump is operated to maintain a stable tank temperature of 60ºC. Though a hysteresis is always managed around the setpoint temperature, this effect is neglected due to the hourly integration step, and therefore we consider that the energy provided by the heat tank is due to the hourly energy demanded by the HVAC to maintain the building rooms at a temperature of 21ºC. Under these conditions, the tank does not act as an energy storage system, and just serves to smooth the operation of the heat pump.

But the heat pump can be also operated as an energy storage system with a variable tank temperature setpoint, decoupling the energy providing by the heat pump from the energy demanded by the HVAC. In this scenario, operation flexibility could be provided under near real time conditions, either increasing or decreasing the tank temperature setpoint and maintaining the same schedule for the HVAC temperature setpoint, and thus the energy demanded by the HVAC which is equal to the previously calculated baseline. For instance, in order to provide flexibility to mitigate RES curtailment in real time, the tank temperature setpoint could be raised, forcing the heat pump to consume more energy in the next hourly period as shown in the next figure, when flexibility is demanded from 9:00 to 10:00 AM.

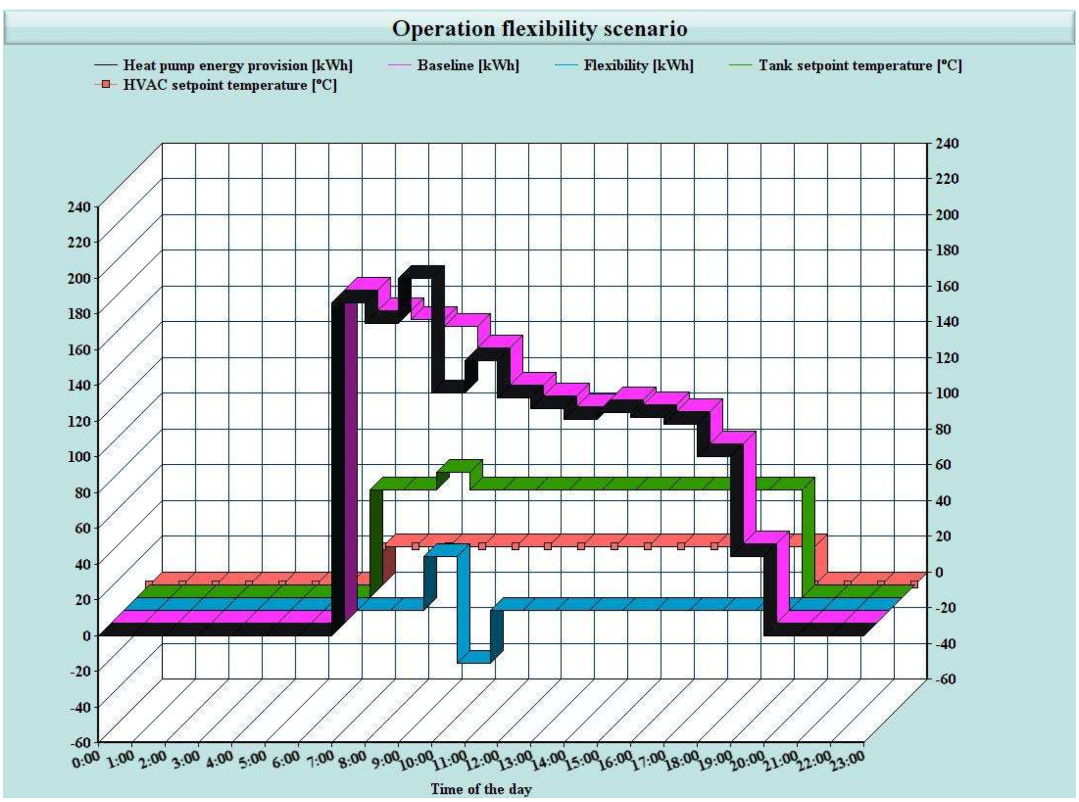

Figure 26: Flexible Heating scenario controlling storage tank setpoint.

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This kind of pre-heating strategy obviously has a certain payback effect on the subsequent period from 10:00 to 11:00, when the tank temperature gets back to its rated value, and therefore the heat pump consumption decreases its value compared to what it was previously scheduled. After that moment, the energy provided by the tank and the energy demanded by the HVAC continue being equal.

In another scenario, flexibility could be provided instead by changing the schedule set point of the building HVAC while maintain the setpoint temperature of the tank. This approach could be followed when flexibility is negotiated with a flex user on a longer period, covering a part of the day. Generally, the energy shift associated to a change in the HVAC setpoint is larger than that derived from using the tank as storage, due to the higher thermal inertia of the building.

In the following figure, we represent the case in which flexibility (consumption increase) is demanded from 9:00 to 12:00 AM. To achieve that consumption increase, HVAC temperature setpoint is increased to 23ºC in that time frame, which is still a temperature under the comfort range decided by the building users.

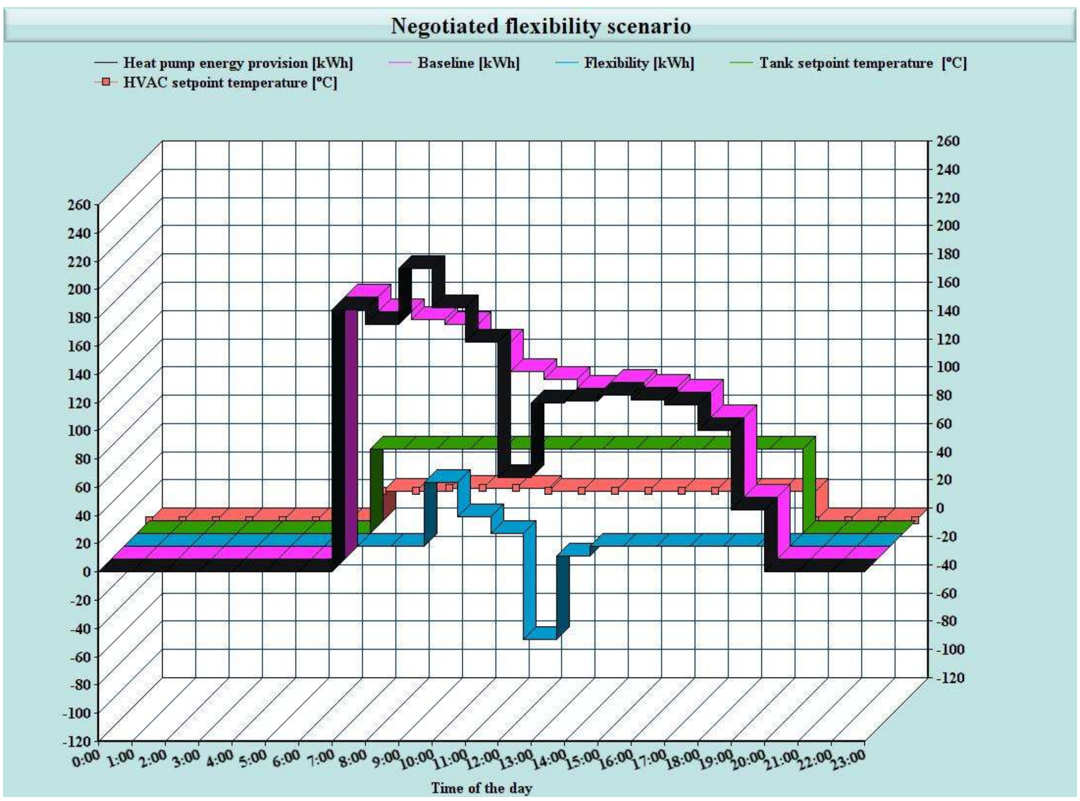

Figure 27: Flexible Heating scenario controlling HVAC tank setpoint.

Of course both ways of providing flexibility could be combined, allowing overlapping variations of both the tank and HVAC temperature setpoint. This combination would be decided depending on the characteristics of the flexibility request, taking into account that the tank operation strategy has a fast effect due to the direct operation trough the heat pump controller, but has inherent limitations due to the sizing of the accumulator tank. As a complement, acting on the HVAC setpoint implies a slower

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response, due to the smoothing effect of the tank, but can achieve higher flexibility rates for longer time periods.

It is also noticeable that when a P2H system is operated, both the flexibility provided in response to a flexibility request and the associated payback can be defined following a different setpoint ramp-up and ramp-down strategy. But this controllability of the flexibility provision is certainly limited by the sizing of the tank and its defined temperature constraints and also by the building thermal inertia and the comfort range decided by the users. These limitations tend to be mitigated when flexibility is provided by a **coalition of P2H systems**, so that the coalition manager can create the conditions in which the flexibility provided by the P2H systems can be shaped to the flexibility that is requested with a higher accuracy.

Using heat-pumps leveraging the flexibility provided by the building thermal inertia, the optional storage tank as an additional buffer, and optional allowed small temperature deviations (under explicit control of the building tenant !) is attractive due to the fact that no major additional investment is needed. The investment is / has been done for the prime goal of heating (and cooling), and the flexibility is provided by a different controlling of the system. However, heat-pumps are not designed for flexibility (though the evolution from on/off heat-pumps to modulating heat pumps is already a big step forward). They are designed for efficiency, and have some inherent characteristics that impose limits on the flexible control one would want to do. Besides, there is no standard control interface for this purpose, so flexibility is either achieved in a rude manner by overriding sensor values, thereby faking a certain context and tricking the heat-pump into taking a certain control action, or by manually reprogramming the controller which is a tedious task. In FHP, we will therefore explore the concept of a **Grid Flexible Heatpump**, which has a standardised flex control interface and less operating restrictions by either making more effective use of its current design, or by proposing design changes.

An important challenge is the **modelling of the building thermal flexibility**. As the thermal capacity is not huge already, such modelling should not be overly-conservative. But at the same time, it must lead to tenant discomfort. And besides, in order to be cost-effective and easy to exploit and replicate, a human-expert free modelling approach is needed. In this project will explore grey-box model creation in such a human-expert free manner, complemented with data-driven machine-learning techniques to tunes these models to both the building specific characteristics, as well as use behaviour which is an important factor as well.

4.2 Ecovat system

Ecovat systems consist of a large underground thermal storage vessel combined with (multiple) Power-to-Heat conversion equipment. This means that disregarding their large size, they are invisible and can integrated in a non-intrusive and space efficient manner close to large residential or commercial neighbourhoods (see Figure 28). Besides, in relation to their volume / storage capacity, their relative surface is small, allowing them to be insulated relatively cheaply, making it possible to store heat over seasons with an efficiency of over 90%. The optimal size of a commercial Ecovat system varies between 10.000 and 70.000 m³ (450 MWh – 3.5 GWh thermal storage). *The prototype that will be used in the Dutch pilot case has a size of 1500 m³ – 70 MWh thermal storage.*

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The Ecovat system is designed as a stratified storage vessel, that can store water at different temperatures in different layers. So, water can be stored at different temperatures for different usages. Water up to 90 °C can for instance be used for tap water. Simultaneously water at 45 °C and 60 °c can be used for floor and radiator heating. It is even possible to use some layers for cooling purposes. The temperature inside the Ecovat typically varies between 0 °C and 95 °C, but these ranges can possibly be extended by adding additives to the water: by doing so, a temperature range from -20 °C to 130 °C. could be achieved.

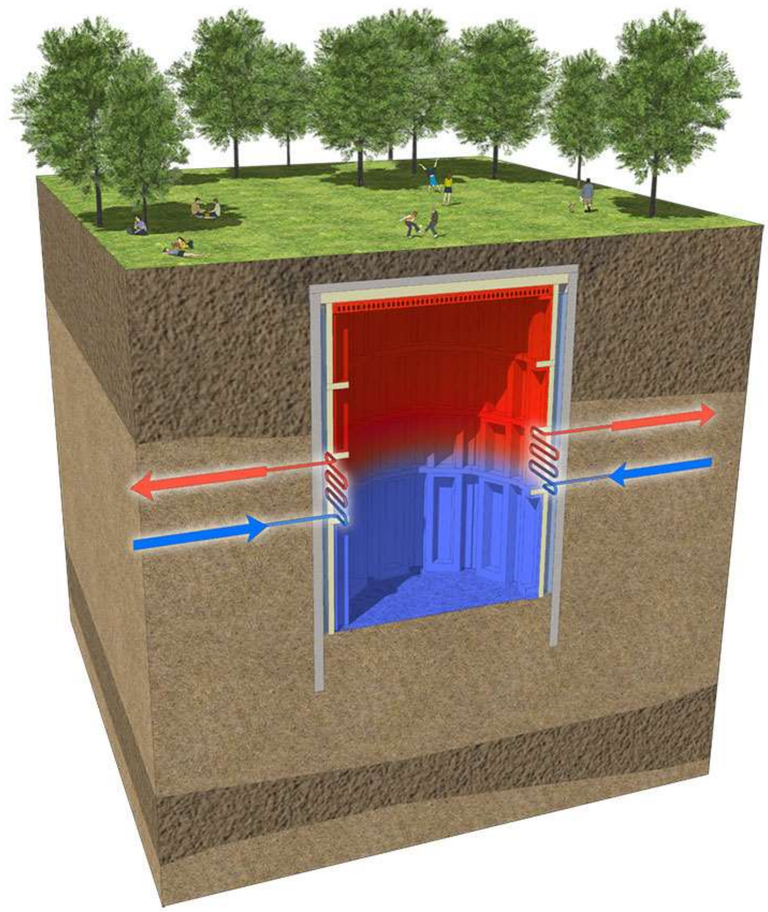

Figure 28: Ecovat underground storage buffer.

The power to heat conversion is done by means of heat exchangers placed in the walls of the system, so no storage water is pumped around. This has two main advantages: (i) ground water can be used as storage medium; (ii) the stratification of the heat is not altered by deployment. Every layer of an Ecovat can be charged and discharged independently from the other layers.

The charging (power to heat conversion) of an Ecovat system can be done using a wide – and combinations – of equipment, like (air-water) heat pumps and thermal resistors. The heat pump is used to provide a background consumption, while the resistor is used to consume large amounts of power in during short periods. In addition, a water-water heat pump can be used to change the exergy by transporting heat from one layer in the Ecovat to another. The latter can also be used if an Ecovat

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is also used for cooling purposes. Besides these typical powers to heat devices, also waste/recovery heat (e.g. from cooling PV installations) could be used to further increase efficiencies.

The prototype that will be used in the Dutch pilot case has following characteristics:

- The heating system consists of 1 water-water heat pump (30 kWth, max temperature 65 °C, min runtime 20 min, min cool-down 10 min), 1 air-water heat pump (20 kWth, max temperature 65 °C, min runtime 20 min, min cool-down 10 min), and 6 industrial heaters (6x28.8 kWe, max temperature 90 °C, no min runtime, no min cool-down) capable of fast response on the order of seconds.
- The industrial heaters are switched in steps of 7.2 kWe with a total power of 173 kWe. However, since the connection to the grid is limited, the industrial heaters are constrained to 150 kW when run simultaneously with heat pumps.
- The temperature and pressure is limited to 90 °C and 3 bar.

The Ecovat is controlled by the Ecovat Control program (ECP). This function block ensures that all safety regulations are followed and actually controls all valves and devices. It monitors and visualizes the state of the system. The ECP is steered by the Ecovat Advice Program (EAP). This module consists of two blocks. The first block measures the state of the Ecovat system and decides which heating devices to turn on, to which layer to provide heat, from which layers to extract heat, etc. It takes these decision, based on the state of the system, the energy price and the time in the year. Its aim is to operate the Ecovat within its physical constraints and the comfort settings of the building(s). The ECP communicates with the Remote Terminal Unit (RTU) on site, who in turn is responsible for the collection of measurements, monitoring of the system, and for implementing control of the heating appliances and fluid system (see **Figure 29**)

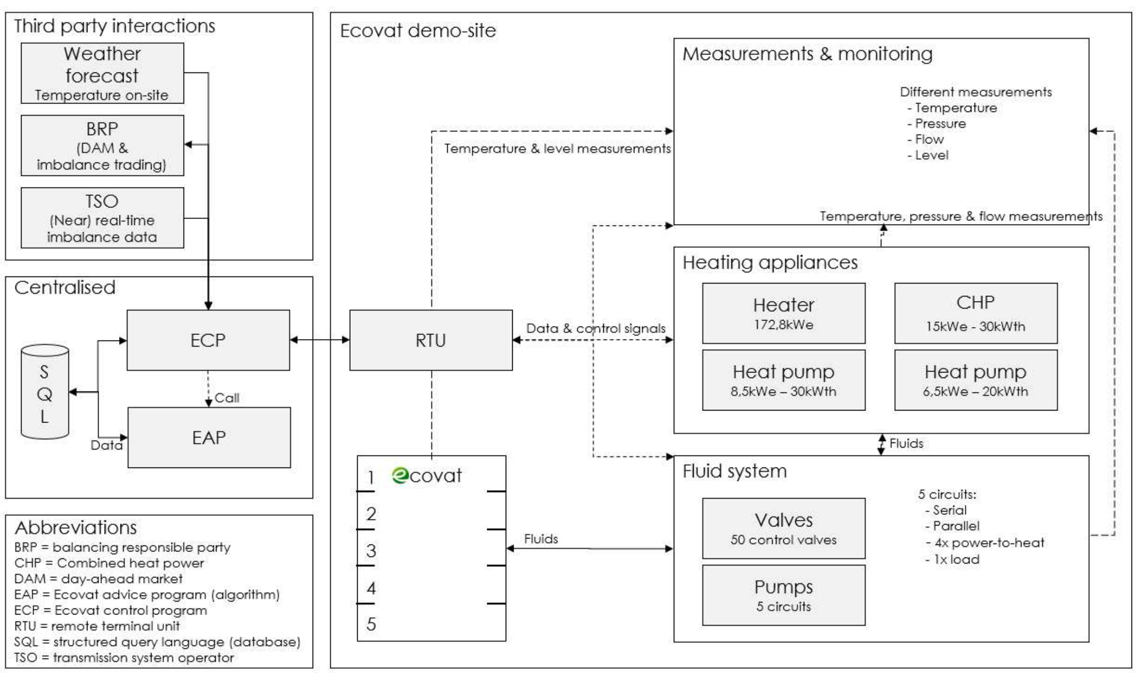

Figure 29: Ecovat system.

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Opportunities and Challenges

- Ecovat systems are well suited for seasonal heat storage, effectively decoupling heat production (e.g. by excess peak solar energy in summer) from heat consumption in winter. They can schedule charging at times when electricity prices are low or negative, typically where there is lot of RES. *We will demonstrate a combination of DA/ID as well as intra-ISP planning (the latter based on intra-ISR forecast information that is provided by the TSO), charging the Ecovat with the max amount of RES, at minimal cost, and significantly reducing market based RES curtailment.*
- The power consumption can technically easily be increased to several MW, but in practice the charging capacity is limited by the grid-connection capacity and cost. *We will propose and demonstrate a dynamic connection capacity, where the connection cost is not (only) determined by the peak capacity, and where there is a coordination with the DSO to enable the Ecovat to use all free grid capacity when its action support the system.*
- The Ecovat system is by no means limited to seasonal storage, but is capable of multiple charging cycles per year. However double taxation on energy storage (firstly, when the energy is bought and stored and, secondly, when the energy is sold to the end consumer) and unfavourable connection tariff structures constrain the operation. *We will analyse the negative effect of such double taxation on the RES curtailment mitigation business cases, as well as the positive effect of more RES friendly taxation system.*
- The Ecovat system is easily able to consume large amount of power during RES production peaks. This is currently not done, due to the high connection costs. However, it is deemed likely that grid congestion will become an active steering parameter in the future, and that taxes and tariff structures will change to encourage beneficial behaviour, presumably by removing tariffs on flexibility provided for the good of the system. There are discussions on changing the tariff structure, and not charge for flexibility provided for the good of the system. *We will analyse the impact of the tariff structures on the RES curtailment mitigation business cases.*

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5 Business Use Cases

In relation to the RES Curtailment Mitigation Business Case, we have associated three Business Use Cases: localRESCurtailmentMitigation, systemRESCurtailmentMitigation and balancingServices.

The localRESCurtailmentMitigation and systemRESCurtailmentMitigation business use cases change flexible P2H consumption schedules based on Day-Ahead and Intra-Day forecasts and checks. If situations/problems are forecasted that would likely result in a decision to curtail RES, either grid-related or market-based, the alternative of changing consumption plans/schedules to avoid the curtailment will be explored. If a solution is found and agreed with flexibility providers, this results in agreed and committed flex activation / P2H setpoints changes / control schedule updates that will take place at the proper time and as agreed. This changed schedule is considered to be a commitment unless if a later agreement overrides it (e.g. based on ID updates, a DA agreed schedule may be changed). The localRESCurtailmentMitigation business use case activates local distribution grid connected P2H flexibility to solve local distribution grid problems that may be caused by local distribution grid connected RES (grid related curtailment). The systemRESCurtailmentMitigation business use case also activates distribution grid connected P2H flexibility, but it does so to avoid market based curtailment of RES. In this case, the RES may be located anywhere, but in order to prevent its curtailment, distribution grid connected P2H resources are used in consultation with the local DSO.

The balancingServices business use case changes flexible P2H consumption schedules based on intra-ISP imbalance forecasts coming from the TSO. If there is a forecasted mismatch with too much generation compared with consumption, this may lead to a decision to curtail RES. This business use case will instead try to increase consumption using distribution grid connected flexible P2H devices.

The localRESCurtailmentMitigation business use case results in an agreed safe **power** flexibility band or profile to which the aggregated (flexible) consumption must adhere. This means for every time-step there is a power value (or band) that must be respected. The systemRESCurtailmentMitigation and balancingServices business uses cases on the other hand lead to an agreed **energy** consumption profile, where for every ISP there is an energy consumption value that must be respected. This gives a higher degree of freedom, as different power profiles could result in the same energy consumption.

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5.1 localRESCurtailmentMitigation

5.1.1 Description of the Business Use Case

Use case identification		
ID	***Area Domain(s)/ Zone(s)***	***Name of use case***
BUC_1	Domains[77]: DER, Distribution, Customer Premises Zones[78]: Process (electricity-heat), Field (Power to Heat appliances control, energy storage, heat pumps control), Operation (DMS, EMS), Market (Energy trading)	localRESCurtailmentMitigation

Scope and objectives of use case	
Scope	If there is excess local RES generation at a distribution grid, this could endanger the safe operation of that distribution grid, and there would be a need to either curtail the local RES, and/or to reinforce the local grid.
Objective(s)	Make it possible for DSOs to forecast (DA and ID) situations where local RES would have to be curtailed, and offer the alternative to activate local flexibility instead of causing (non-transparent) or requesting local RES curtailment. This way, to minimize instances where avoidable RES curtailment would be decided. **Resulting in an optimal flex activation plan and resulting consumption profile schedule update that is within a safe flex band provided by the DSO.**
Demo Site	Karlhshamn, Sweden

[77] SGAM Domains (see section 7.2.4 of (CENELEC, 2012)

[78] SGAM Zones (see section 7.2.5 of (CENELEC, 2012)

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Narrative of use case
Short description
DSOs forecast (DA and ID) the need to curtail RES due to excessive local generation. They will try to avoid the local RES curtailment by activating local flexibility to absorb the excess RES energy. Specifically, P2H flexibility will be used by adapting consumption profiles to consume more when there is too much RES. By means of Flex Requests by the DSO and Flex Offers by the DCMs, an (optimal) Flex Order is negotiated and the consumption plans of the P2H devices are adapted accordingly.
Complete description
Heat Providers determine an optimal P2H consumption profile for their Heat Users, and the DCMs determine an optimal aggregated total consumption profile of all active buildings or P2H assets (like an Ecovat system) that they have contracted. More specifically, an aggregation per grid zone is done. This total consumption profile also contains a forecast of the non-P2H consumption. These DCM total consumption profiles are provided to the DSO who combines this with additional own forecasts (e.g. of local RES installations). With this, and an available grid model and information, a Load Flow Check (per grid zone) is done to determine whether there are problems. If there are problems, the DSO creates a Flex Request (per grid zone) for the DCMs, who respond to this with Flex Offers that are created by negotiation with their Heat providers. These Flex Offers are aggregated by the DSO (per grid zone) and the resulting flex is checked against sufficiency (i.e. solving the problem and not causing new problems) and affordability (not too expensive). If needed, adjusted flex requests are created and new iterations are done until a solution is found or until it is decided that there is no (affordable) solution in which case no flex will be activated and curtailment will likely take place. If a solution is found, Flex Orders that correspond to the successful Flex Offer are sent to the DCMs, to disaggregate this to their Heat Providers, who disaggregate this to their Heat Users, and change the Heat Users plans accordingly. The DCMs as well aggregate the agreed flexibility activation per BRP (balancing group) and inform BRPs about that, so they can adjust their own consumption and generation forecasts. Instead of trying to forecast what flexibility will be activated, BRPs are informed about what flexibility will be activated, which is much more precise. This allows them to make better informed bids/offers to the market.

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The above process (sequence of steps) runs DA (agreeing and adapting consumption plans between Start of Day till End of Day for all ISPs) and can be repeated ID with a shrinking horizon (agreeing and adapting consumption plans for all future ISPs till End of Day). Each time the process runs, this results in a formal agreement and planning update, but this can be re-negotiated and re-agreed each successive (ID) time that the process runs.

Use case conditions
Assumptions
▪ BRPs make their own consumption and generation forecasts for their portfolio very similarly as of today. But they receive additional information on flexibility that will be activated, so they can use this information to make better informed bids to the markets (e.g. correcting their baseline bids that they would forecast in the absence of flex activations). I.e. the BRP does not need to try to forecast what flex activations might be done, but he is informed about what flex activations will be done, so he can do a better-informed bids/offers to the market. ▪ Flexibility providers are willing and obliged to activate flexibility if the offered incentive at least covers the (objective) cost of the activation, so there is no absolute Freedom to Dispatch.
Prerequisites
▪ DSOs have an up-to-date grid model. ▪ DSOs know what Heat Providers are contracted by which DCMs (this is rather static information): they need this information to define the Grid Zones for each DCM (if there are multiple), and they need this to know what consumption forecasts they must make themselves (of non-active buildings, that are not contracted by a DCM) versus what forecasts they can expect to receive from DCMs. ▪ DCMs know the Balancing Group (it is rather static information): they know what Heat Providers are contracted by which BRP. They need this information to know which BRP to inform about which agreed flexibility activation.

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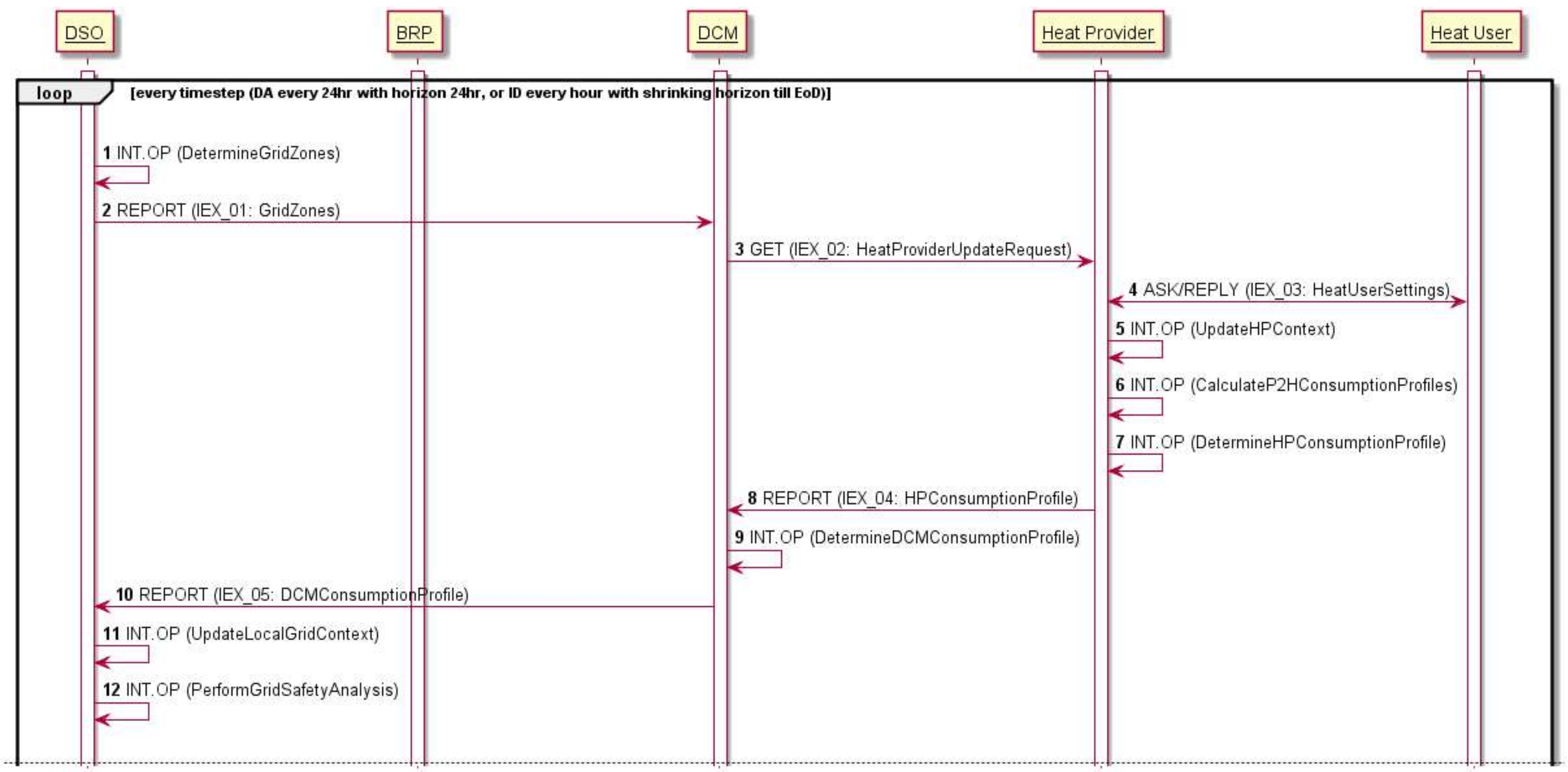
5.1.2 Diagram of the Use Case

Diagram(s) of use case
Sequence diagram: 

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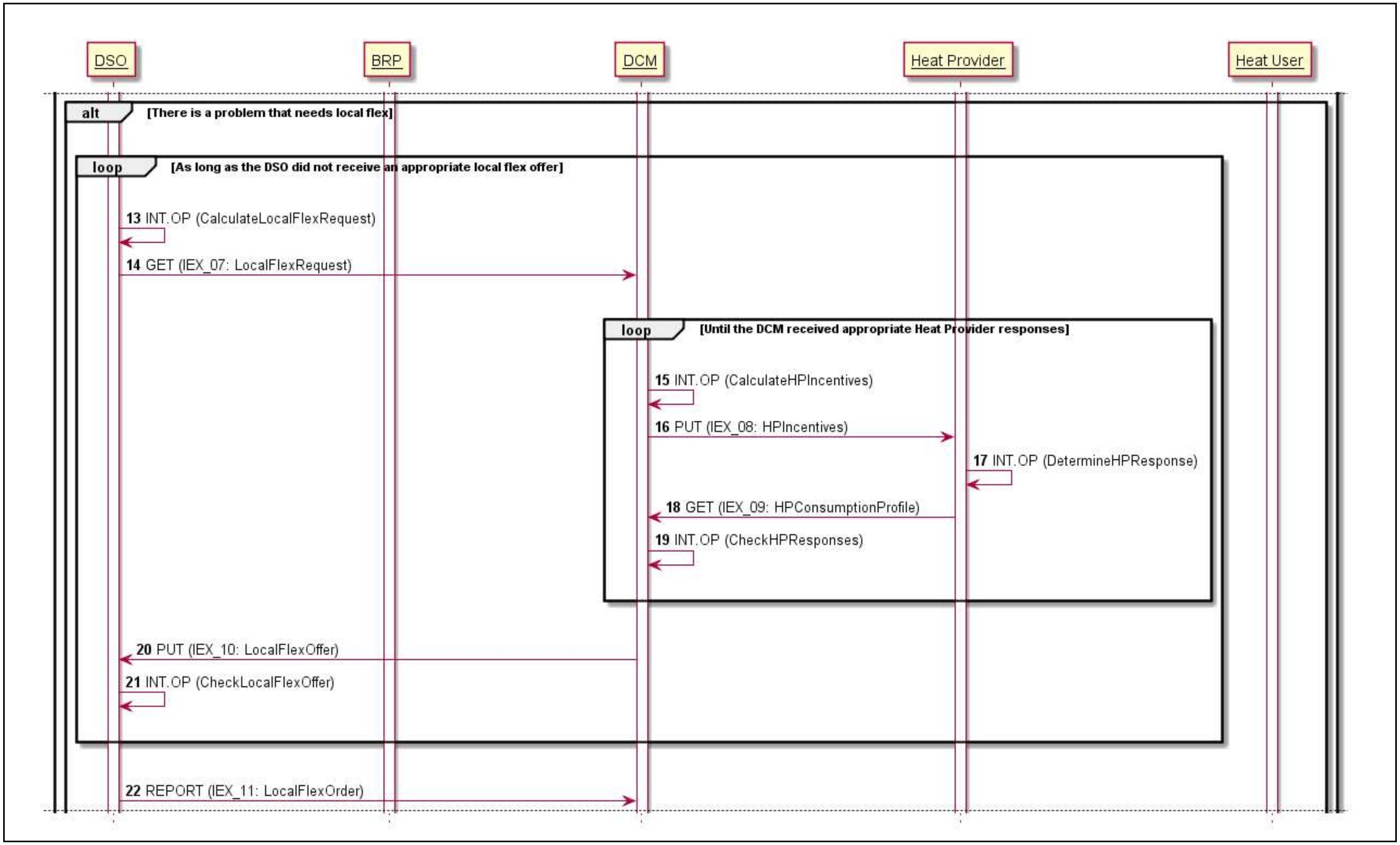

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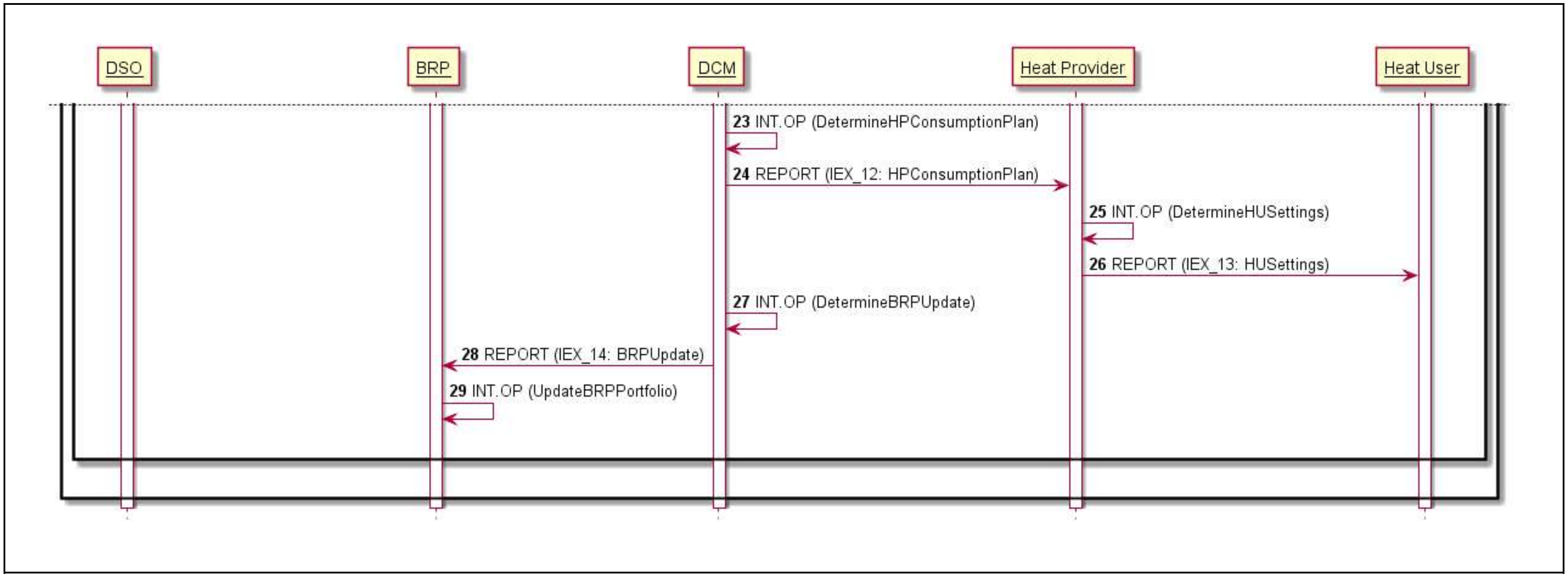

5.1.3 Step by step analysis of use case

Scenarios						
No.	***Scenario name***	***Scenario description***	***Primary beneficiaries***	***Triggering event***	***Pre-condition***	***Post-condition***
1	No exceptions	An appropriate Local Flex Offer is found in response to each Local Flex Request.	*DSO, DER Producer*	Time Trigger		

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Scenario 1							
Scenario name:		No exceptions					
Step No.	***Name of process/ activity***	***Description of process/ activity***	***Service***	***Information producer (actor)***	***Information receiver (actor)***	***Information exchanged (IDs)***
1	Determine GridZones	Decide which connection points can be clustered	Internal Processing	DSO	DSO	—
2	Send GridZones	Send list of grid zones with associated connection points to each DCM	REPORT	DSO	DCM	IEX_01
3	Send Heat Provider Update Request	Request Heat Providers to provide the latest information	GET	DCM	Heat Provider	IEX_02
4	Get Heat User settings	Retrieve actual comfort, temperature and willingness to offer flex information	ASK/REPLY	Heat Provider	Heat User	IEX_03
5	Update Heat Provider Context	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)	Internal Processing	Heat Provider	Heat Provider	—
6	Calculate P2H Consumption Profiles	Calculate admissible P2H consumption profiles	Internal Processing	Heat Provider	Heat Provider	—
7	Determine Heat Provider Consumption Profile	Select most optimal profile from all calculated ones.	Internal Processing	Heat Provider	Heat Provider	—

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8	Send Heat Provider Consumption Profile	Send optimal baseline profile	PUT	Heat Provider	DCM	IEX_04
9	Determine DCM Consumption Profile	Create aggregated baseline plan per Grid Zone	Internal Processing	DCM	DCM	—
10	Send DCM Consumption Profile	Send aggregated baseline plan per Grid Zone	REPORT	DCM	DSO	IEX_05
11	Update Local Grid Context	Update (and retrieve) additional information that is needed for doing the local grid check	Internal Processing	DSO	DSO	—
12	Perform Grid Safety Analysis	Perform a Load Flow Check	Internal Processing	DSO	DSO	—
	IF_1 THERE IS A PROBLEM THAT NEEDS LOCAL FLEX					
	LOOP_1 AS LONG AS THE DSO DID NOT RECEIVE AN APPROPRIATE LOCAL FLEX OFFER					
13	Calculate Local Flex Request	Determine what local flex request to send to which DCM.	Internal Processing	DSO	DSO	—
14	Send Local Flex Request	Send a local flex request to each DCM	REPORT	DSO	DCM	IEX_07
	LOOP_2 UNTIL THE DCM RECEIVED APPROPRIATE HEAT PROVIDER RESPONSES					
15	Calculate Heat Provider Incentives	Determine what incentive to send to which Heat Provider	Internal Processing	DCM	DCM	—
16	Send Heat Provider Incentive	Send a shadow price profile.	PUT	DCM	Heat Provider	IEX_08

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17	Determine Heat Provider Response	Calculate optimal P2H consumption profile for the received incentive / price profile	Internal Processing	Heat Provider	Heat Provider	—
18	Send Heat Provider Consumption Profile	Send the optimal P2H consumption profile for the received incentive / price profile	GET	Heat Provider	DCM	IEX_09
19	Check Heat Provider Responses	Aggregate all received P2H consumption profiles and check whether good enough (exit LOOP_2) or do another iteration	Internal Processing	DCM	DCM	—
	END LOOP_2					
20	Send Local Flex Offer	Send the DCM local flex offer in response to the received local flex request (this can as well be a 'no offer' message if LOOP_2 was exited without an appropriate local flex offer has been found)	REPORT	DCM	DSO	IEX_10
21	Check Local Flex Offer	Check the combination of all received DCM Local Flex Offers and decide whether good enough (exit LOOP_1) or do another iteration. (the LOOP_1 will also be exited if no appropriate solution can be found: in this case, the whole process stops and the DSO will partially curtail)	Internal Processing	DSO	DSO	—
	END LOOP_1					
22	Send Local Flex Order	Confirm each accepted local flex offer by sending a local flex order	REPORT	DSO	DCM	IEX_11

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22	Determine Heat Provider Consumption Plan	Disaggregate the received flex order into a consumption plan per Heat Provider	Internal Processing	DCM	DCM	—
24	Send Heat Provider Consumption Plan	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)	REPORT	DCM	Heat Provider	IEX_12
25	Determine Heat User Settings	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User. Determine the corresponding P2H setpoints for the Heat User	Internal Processing	Heat Provider	Heat Provider	—
26	Send Heat User Settings	Update Heat User's P2H setpoints (e.g., control plan for the heat pump)	REPORT	Heat Provider	Heat User	IEX_13
27	Determine BRP Update	Determine the flex activation plan corresponding to the received flex order per balancing group (BRP)	Internal Processing	DCM	DCM	—
28	Send BRP Update	Inform the BRP about the planned/scheduled flex activations that relate to his balancing group.	REPORT	DCM	BRP	IEX_14
29	Update BRP Portfolio	Adjust the BRP consumption forecast with the received flex activation schedule information (improve the accuracy of the bids that will be made to markets)	Internal Processing	BRP	BRP	—
	END IF_1					

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5.2 systemRESCurtailmentMitigation

5.2.1 Description of the Business Use Case

Use case identification		
ID	***Area Domain(s)/ Zone(s)***	***Name of use case***
BUC_2	Domains[79]: DER, Distribution, Customer Premises Zones[80]: Process (electricity-heat), Field (Power to Heat appliances control, energy storage, heat pumps control), Operation (EMS), Market (Energy trading)	systemRESCurtailmentMitigation

Scope and objectives of use case	
Scope	If there is excess system RES generation, causing too low or negative prices, this may invoke a BRP to consider curtailing his RES generation.
Objective(s)	Make it possible for BRPs to forecast (DA and ID) situations where a market-based decision would be taken to curtail RES because of too much generation / too low consumption. Offer the alternative to activate P2H flexibility connected to distribution grids and this way increase consumption instead of curtailing RES generation. **Resulting in an optimal flex activation plan and resulting consumption profile schedule update that adheres to the with the BRP agreed energy consumption plan (aggregated power per ISP), and optionally within a safe flex band provided by the DSO.**
Demo Site	Uden (the Netherlands) and Karlshamn (Sweden)

[79] SGAD Domains (see section 7.2.4 of (CENELEC, 2012)

[80] SGAD Zones (see section 7.2.5 of (CENELEC, 2012)

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Narrative of use case
Short description
BRPs forecast (DA and ID) the economical optimal decision to curtail RES due to excessive generation compared to consumption. They will try to avoid such RES curtailment by activation of distribution grid connected flexibility to increase the amount of consumption to absorb the excess RES energy. Specifically, P2H flexibility will be used by adapting consumption profiles to consume more when there is too much RES. By means of flex offers by the DCMs and flex requests by the BRPs, an (optimal) flex order is negotiated and the consumption plans of the P2H devices are adapted accordingly.
Complete description
Heat Providers determine and optimal P2H consumption profile as well as flexibility profiles (or a flexibility model) for their Heat Users, and the DCMs determine an optimal aggregated total consumption profile as well as flexibility profiles (or a flexibility model) of all active buildings or P2H assets (like Ecovat) that they have contracted. More specifically, an aggregation per balancing group (BRP) is done. These aggregated flexibility profiles (or flexibility models) are offered to BRPs, and based on a forecast of his portfolio the BRP may request flexibility from DCMs so that no RES curtailment is needed. ***(note: another business use case variant can be considered, where the DCM only issues a Flex Offer in response to a Flex Request received from a BRP)*** The DCMs combine these received flex orders with the optimal total consumption profiles of the Heat Providers, and aggregate these per grid zone, to provide the DSO with the proposed planned consumption profiles. The DSO combines these with additional own forecasts (e.g. of local RES installations and non-active buildings). With this, and an available grid model and information, a Load Flow Check (per grid zone) is done to determine with the planned activation would lead to a local grid problem. If there would be problems, the DSO creates a Flex Request (per grid zone) for the DCMs, who respond to this with Local Flex Offer created by negotiation with their Heat Providers. These local Flex Offers are aggregated by the DSO (per grid zone) and the resulting flex is checked against its sufficiency (i.e. solving the problem and not causing new problems) and affordability (not too expensive). If needed, adjusted flex requests are created and new iterations are done until a solution is found or until it is decided that there is no (affordable) solution that is accepted by the DCM. If a solution is found and accepted by the DCM, the DCM will calculate a new adapted system flex offer – which when requested would not cause a local problem - for the BRP and send this to the BRP to receive a next flex offer that would not cause a local problem.

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If no acceptable solution is found for the DCM, the DCM will inform the DSO that no adaptations will be done to solve the local problem (meaning the DSO has to solve it himself in another manner), and informs the BRP that the system flex offer is accepted. The BRP then issues a corresponding system flex order to the DCM, who can disaggregate this to his Heat Providers, who disaggregate this to their Heat Users and change the Heat Users plans accordingly.

The BRPs can adjust their own consumption and generation forecasts with the now agreed planned and scheduled flexibility activation, improving their forecast and bids/offers to the market.

The above process (sequence of steps) runs DA (agreeing and adapting consumption plans between Start of Day till End of Day for all ISPs) and can be repeated ID with a shrinking horizon (agreeing and adapting consumption plans for all future ISPs till End of Day). Each time the process runs, this results in a formal agreement and planning update, but this can be renegotiated and re-agreed each successive (ID) time that the process runs.

Notes:

The above business use case variant is closest to what is proposed by the USEF framework. DCMs have the option to freely and in an unconstrained manner collect flex requests from BRP to maximize their own business case. They will inform the DSO though, so that this one can do a check of the impact on the local grid, and if there is a problem, can ask the DCM to change his activation plan (hence his offer to the BRP) in return for an incentive. However, the DCM has Freedom to Dispatch and is free to decide whether or not he accepts the DSO Local Flex Request. If not, he DSO will have to find other (emergency) means to resolve the problem, yet at least he is informed in advance. If the DCM does accept the DSO Local Flex request (e.g. because the offered incentive outweighs the expected smaller or lost incentive from the BRP), a new negotiation with the BRP must start.

As a first alternative, one could decide that the DCM has no absolute Freedom to Dispatch, and must change his activation plan on request of the DSO, in a way that is strictly governed by updated regulation.

A second alternative would be that the DCM asks the DSO about the safe flex bands upfront, and offers to the BRP only flexibility that is within this safe flex band. This way, by definition the flex offer that is made to the BRP, and the resulting flex request, will not violate any local grid constraints (and no explicit check of the request is needed even). Of course, this alternative will limit the DCM in his freedom to operate.

Use case conditions

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Assumptions
▪ This Business Use Case describes a proposed future interaction scheme between energy system participants, requiring a change in their roles and responsibilities, as well a regulation. This is inspired by the work done in the Universal Smart Energy Framework[81]. ▪ BRPs make their own consumption and generation forecasts for their portfolio similarly as of today. They receive from DCMs information on available forecasted flexibility and cost, which they can use to optimize their portfolio and decisions, especially in relation to minimizing market based RES curtailment. ▪ The System Flex Requests that turn into System Flex Orders are agreed bilaterally between the BRP and the DCM (OTC) i.e. the increased consumption is not offered by the BRP to the market. ▪ If DCMs also run the localRESCurtailmentMitigation Business Use Case, these processing steps are run before the steps related to this systemRESCurtailmentMitigation Business Use Case. This means that local flexibility is offered and used first to resolve local problems, and only remaining flex is offered for system level services. In this case, there is a commitment towards the DSO to NOT violate the local grid constraints..
Prerequisites
▪ The DSO has an up-to-date grid model ▪ The DSO knows what Heat Providers are contracted by which DCMs (this is rather static information): he needs this information to define the Grid Zones for each DCM (if there are multiple), and he needs this to know what forecasts he must make himself versus what forecasts he can expect to receive from which DCM ▪ The DCM knows the Balancing Group (i.e. it is rather static information): they know what Heat Providers are contracted by which BRP. They need this information to know which aggregated flexibility to offer to which BRP.

[81] USEF: www.usef.energy

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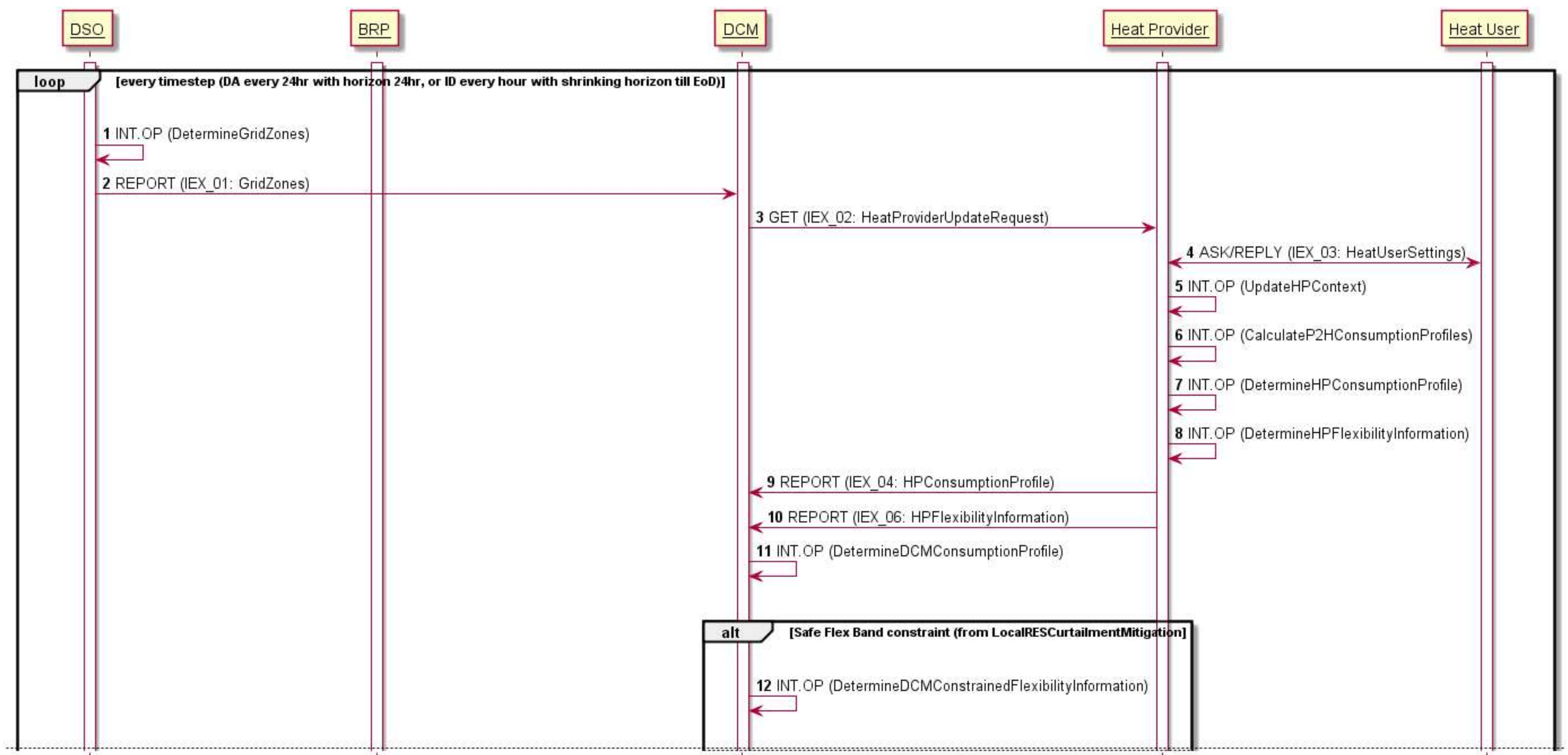
5.2.2 Diagrams of use case

Diagram(s) of use case
Sequence diagram: 

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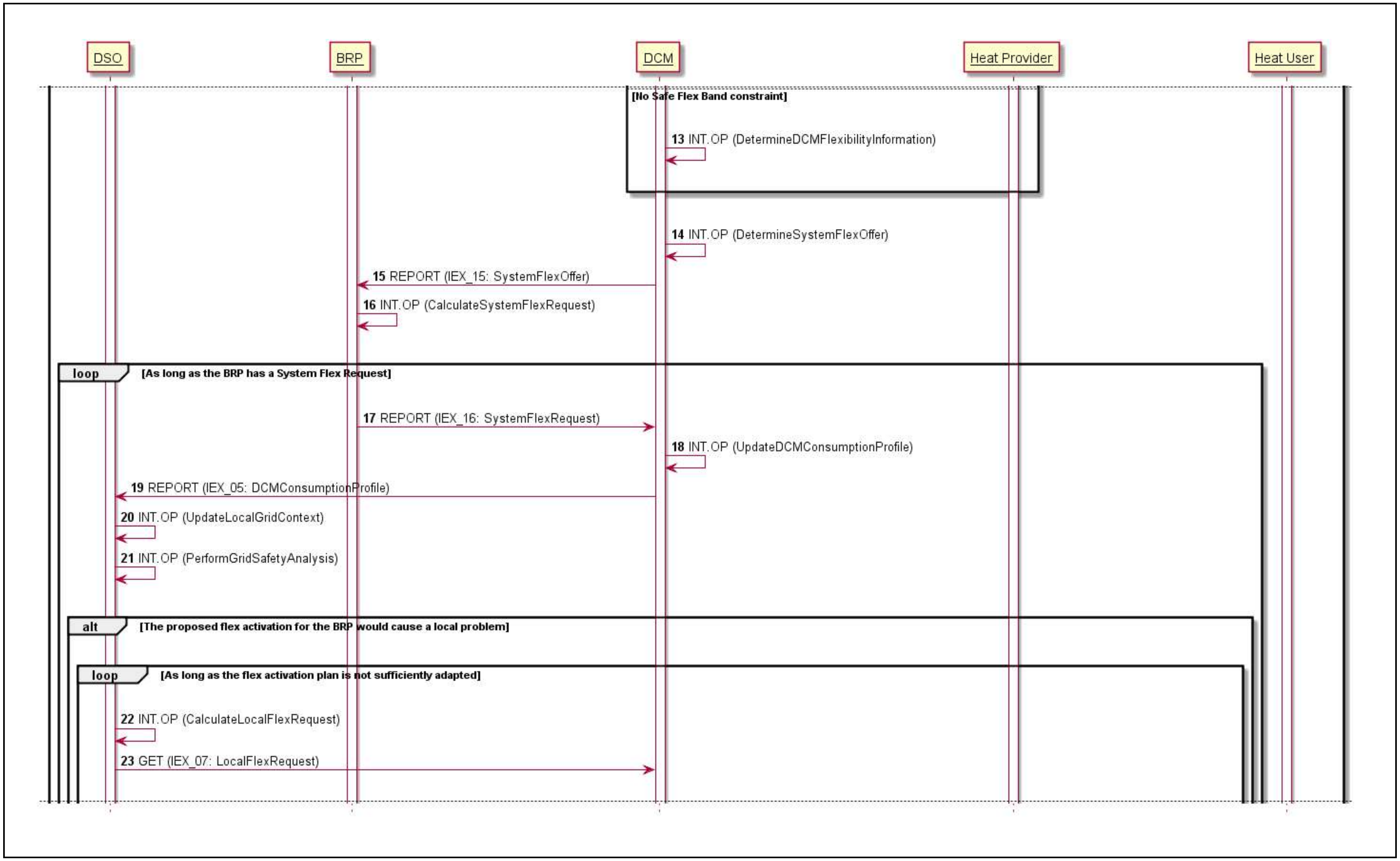

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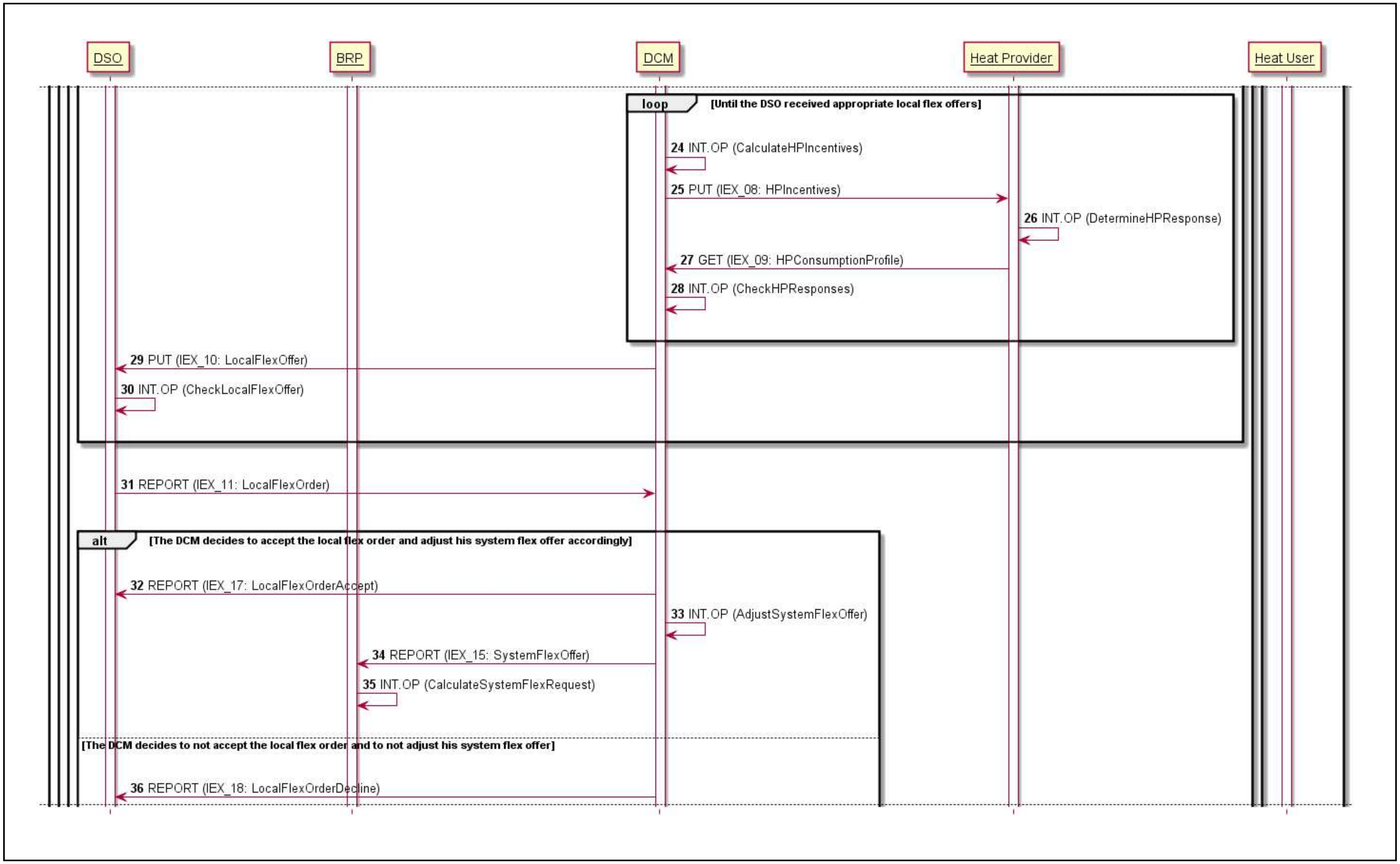

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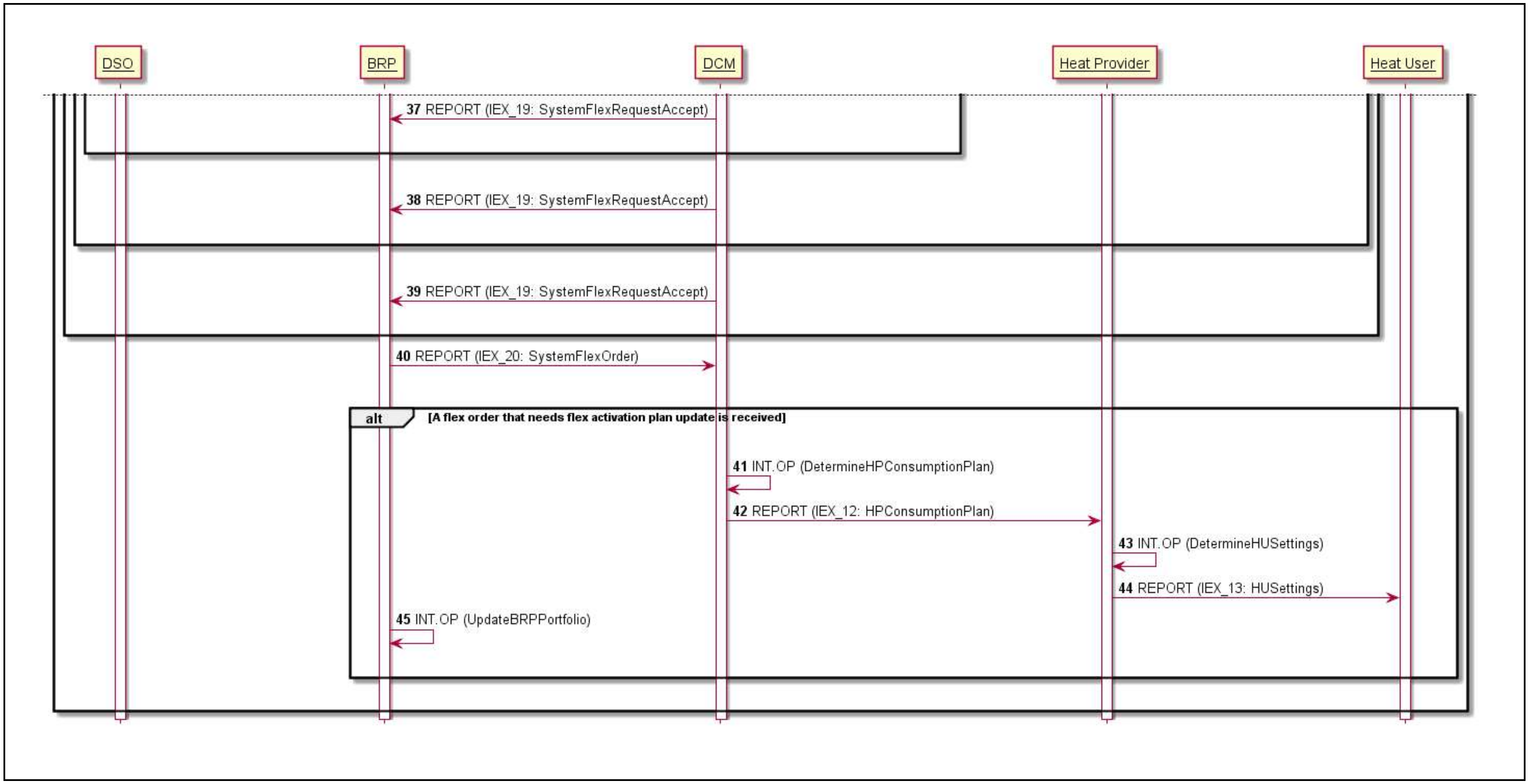

5.2.3 Step by step analysis of use case

Scenarios

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No.	Scenario name	Scenario description	Primary beneficiaries	Triggering event	Pre-condition	Post-condition
1	Normal operation unconstrained	The flex offer to the BRP is done without upfront checking what can be offered in a local grid secure manner. This means that if the BRP places an order, the DCM must check this order with the DSO, who gets the chance to ask for a change. The DCM has the freedom to alter his offer to the BRP to accommodate the DSO, or not.	*BRP, DER Producer*			
2	Normal operation - constrained	The DCM could first ask the DSO what the allowed flex band is, and only offer to the BRP something that fits in this band. This means that any order placed by the BRP can be accommodated without needing additional checks and iterations. But the DCM would be constrained in what he can earn from the BRP and even does not know how much he is losing.	*BRP, DER Producer*			

Scenario 1						
Scenario name :		Normal operation - unconstrained				
Step No.	**Name of process/ activity**	**Description of process/ activity**	**Service**	**Information producer (actor)**	**Information receiver (actor)**	**Information exchanged (IDs)**
1	Determine GridZones	Decide which connection points can be clustered	Internal Processing	DSO	DSO	—
2	Send GridZones	Send list of grid zones with associated connection points to each DCM	REPORT	DSO	DCM	IEX_01

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3	Send Heat Provider Update Request	Request Heat Providers to provide the latest information	GET	DCM	Heat Provider	IEX_02
4	Get Heat User settings	Retrieve actual comfort, temperature and willingness to offer flex information	ASK/REPLY	Heat Provider	Heat User	IEX_03
	The next steps are needed to determine the planned optimal baseline consumption profile as well as flexibility. The latter is needed for creating flex offers to BRPs; The former is needed to combine with proposed BRP Flex Orders to check with DSO.					
5	Update Heat Provider Context	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)	Internal Processing	Heat Provider	Heat Provider	—
6	Calculate P2H Consumption Profiles	Calculate admissible P2H profiles	Internal Processing	Heat Provider	Heat Provider	—
7	Determine Heat Provider Consumption Profile	Select most optimal profile from all calculated ones.	Internal Processing	Heat Provider	Heat Provider	—
8	Determine Heat Provider Flexibility Information	Determine available flexibility (in relation to the optimal baseline consumption profile)	Internal Processing	Heat Provider	Heat Provider	—
9	Send Heat Provider Consumption Profile	Send optimal baseline profile	PUT	Heat Provider	DCM	IEX_04
10	Send Heat Provider Flexibility Information	Send flexibility information	PUT	Heat Provider	DCM	IEX_06

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11	Determine DCM Consumption Profile	Create aggregated baseline plan per Grid Zone	Internal Processing	DCM	DCM	—
	IF_1 Safe Flex Band Constraint (from localRESCurtailmentMitigation)					
12	Determine DCM **Constrained** Flexibility Information	Determine the cluster flexibility information based on the received flex information from all Heat Providers (using knowledge of balancing groups)	Internal Processing	DCM	DCM	—
	ELSE_1					
13	Determine DCM Flexibility Information	Determine the cluster flexibility information based on the received flex information from all Heat Providers (using knowledge of balancing groups)	Internal Processing	DCM	DCM	—
	END IF_1					
14	Determine System Flex Offer	Calculate Flex Offer(s) (flex products) based on the determined flex model per balancing group	Internal Processing	DCM	DCM	—
15	Send System Flex Offer	Send System flex offers to BRP	REPORT	DCM	BRP	IEX_15
16	Calculate System Flex Request	BRP calculates if, how much and when flex would be needed (to mitigate system RES curtailment)	Internal Processing	BRP	BRP	—
	LOOP_1 UNITL NO MORE FLEX REQUEST NEEDED					
17	Send System Flex Request	Send System Flex Requests(s)	REPORT	BRP	DCM	IEX_16

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18	Update DCM Consumption Profile	Calculate proposed updated DCM local consumption profile (optimal baseline profile off-set with SystemFlexRequest = BRP proposed flex order)	Internal Processing	DCM	DCM	—
19	Send DCM Consumption Profile	Send aggregated baseline plan per grid zone	REPORT	DCM	DSO	IEX_05
20	Update Local Grid Context	Update (and retrieve) additional information that is needed for doing the local grid check	Internal Processing	DSO	DSO	—
21	Perform Grid Safety Analysis	Perform a Load Flow Check	Internal Processing	DSO	DSO	—
	IF_2 THE PROPOSED FLEX ACTIVATION FOR THE BRP WOULD CAUSE A LOCAL PROBLEM					
	LOOP_2 AS LONG AS THE FLEX ACIVATION PLAN IS NOT SUFFICIENTLY ADAPTED					
22	Calculate Local Flex Request	Determine what local flex request to send to the DCM	Internal Processing	DSO	DSO	—
23	Send Local Flex Request	Send a local flex request to the DCM	REPORT	DSO	DCM	IEX_07
	LOOP_3 UNTIL AN OPTIMAL OR SATISFACTORY SOLUTION IS FOUND					
24	Calculate Heat Provider Incentives	Determine what incentive to send to which Heat Provider	Internal Processing	DCM	DCM	—
25	Send Heat Provider Incentive	Send a shadow price profile.	PUT	DCM	Heat Provider	IEX_08

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26	Determine Heat Provider Response	Calculate optimal P2H consumption profile for the received incentive / price profile	Internal Processing	Heat Provider	Heat Provider	—
26	Send Heat Provider Consumption Profile	Send the optimal P2H consumption profile for the received incentive / price profile	GET	Heat Provider	DCM	IEX_09
28	Check Heat Provider Responses	Aggregate all received P2H consumption profiles and check whether good enough (exit LOOP_2) or do another iteration	Internal Processing	DCM	DCM	—
	END LOOP_3					
29	Send Local Flex Offer	Send the DCM local flex order in response to the received local flex request (this can as well be a 'no offer' message if LOOP_2 was exited without an appropriate local flex offer has been found)	REPORT	DCM	DSO	IEX_10
30	Check Local Flex Offer	Check the received local flex offer and decide whether good enough (exit LOOP_1) or do another iteration. (the LOOP_1 will also be exited if no appropriate solution can be found: in this case, the whole process stops and the DCM will not adapt the system flex activation plan)	Internal Processing	DSO	DSO	—
	END LOOP_2					
31	Send Local Flex Order	Confirm accepted local flex offer by sending a local flex order	REPORT	DSO	DCM	IEX_11

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		In this case, this order is still a proposed order because the DCM has the right to bail out because of Freedom to dispatch; so, in this case (in contrast to localRESCurtailmentMitigation) an explicit confirmation is needed by the DCM to the DSO				
	IF_3 THE DCM DECIDES TO ACCEPT THE LOCAL FLEX ORDER AND ADJUST HIS SYSTEM FLEX OFFER					
32	Send Local Flex Order Accept	Confirm to DSO the acceptance of the local flex order	REPORT	DCM	DSO	IEX_17
33	Adjust System Flex Offer	Recalculate/reshape the System Flex Offer so that it fits the local flex order.	Internal Processing	DCM	DCM	—
34	Send System Flex Offer	Send updated System flex offers to BRP This means that the BRP receives a new System Flex Offer – this time within the DSO cleared safe flex band – so that any matching System Flex Request can be honoured without causing local grid problems	REPORT	DCM	BRP	IEX_15
35	Calculate System Flex Request	BRP calculates if, how much and when flex would be needed (to mitigate system RES curtailment)	Internal Processing	BRP	BRP	—
	ELSE_3 USE FREEDOM TO DISPATCH AND DECIDE TO NOT ADAPT THE SYSTEM FLEX OFFER TO FULLFILL THE LOCAL FLEX REQUEST					
36	Send Local Flex Order Decline	Inform DSO that no local flex service will be provided	REPORT	DCM	DSO	IEX_18
37	Send System Flex Request Accept	Inform BRP that the system flex request is accepted	REPORT	DCM	BRP	IEX_19

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	END IF_3					
38	Send System Flex Request Accept	Inform BRP that the system flex request is accepted	REPORT	DCM	BRP	IEX_19
	END IF_2					
39	Send System Flex Request Accept	Inform BRP that the system flex request is accepted (so no more flex request needed)	REPORT	DCM	BRP	IEX_19
	END LOOP_1					
40	Receive System Flex Order	BRP confirms the system flex request with a system flex order (can be No Order is no acceptable solution was found)	REPORT	BRP	DCM	IEX_20
	IF_3 A FLEX ORDER IS RECEIVED					
41	Determine Heat Provider Consumption Plan	Disaggregate the received system flex order into a plan per Heat Provider	Internal Processing	DCM	DCM	—
42	Send Heat Provider Consumption Plan	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)	REPORT	DCM	Heat Provider	IEX_12
43	Determine Heat User Settings	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User. Determine the corresponding P2H setpoints for the Heat User.	Internal Processing	Heat User	Heat User	—

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44	Send Heat User Settings	Update Heat User's P2H setpoints (e.g. control plan for the heat pump)	REPORT	Heat Provider	Heat User	IEX_13
45	Update BRP Portfolio	Update the BRP consumption forecast with the flex activation schedule information corresponding to the agreed system flex order (improve the accuracy of the bids that will be made to market)	Internal Processing	BRP	BRP	—
	END IF_3					

5.3 balancingServices

5.3.1 Description of the Business Use Case

Use case identification

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ID	Area Domain(s)/ Zone(s)	Name of use case
BUC_3	Domains[82]: DER, Distribution, Customer Premises Zones[83]: Process (electricity-heat), Field (Power to Heat appliances control, energy storage, heat pumps control), Operation (EMS), Market (Energy trading)	balancingServices

Scope and objectives of use case	
Scope	If there is forecasted excess (RES) generation in the current ISP, causing negative imbalance prices, BRPs may be inclined to curtail their RES to avoid these imbalance costs. This is especially true if BRPs are informed about the forecasted imbalance during the current ISP by the TSO, as in the Netherlands. Note: Real-time balance deviations in generally are taken care of by the TSO, i.e., the TSO monitors the imbalance and has reserves providing resources contracted/reserved to fix the balance and these are activated within the agreed reservation based on real-time observations and control signals. The TSO afterwards attributes the imbalances to the BRPs, and these pay an imbalance penalty for the imbalances they caused. The imbalances and related penalties are only known after the ISP. An alternative approach – which is in use in the Netherlands – is that the TSO in the beginning of the ISP (e.g., after 2') provides information on the system balance and the resulting forecasted imbalance prices for the ISP period, so that BRPs could decide to act on this information, resulting in less activations that are needed by the TSO himself.
Objective(s)	Avoiding real-time (intra-ISP) RES curtailment by BRPs as a way to reduce imbalance costs by enabling them to fix forecasted intra-ISP imbalances themselves by increasing consumption plans of flexible P2H resources in the current ISP to compensate for the forecasted excess generation.

[82] SGAD Domains (see section 7.2.4 of (CENELEC, 2012)

[83] SGAD Zones (see section 7.2.5 of (CENELEC, 2012)

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	Resulting in a with the BRP agreed energy consumption plan for the current ISP. That is, it is an intra-ISP energy consumption planning update on request of the BRP and within a safe flex band provided by the DSO.
Demo Site	Uden, the Netherlands

Narrative of use case
Short description
TSO forecasts (intra-ISP) excess generation causing negative imbalance prices. BRPs will try to avoid this by curtailing RES generation. As an alternative to this, they can try to activate P2H flexibility to absorb the excess RES energy. Based on Flex Offers from the DCMs that are in a DSO specified Safe Flex Capacity band, BRPs can order intra-ISP energy consumption schedule adaptations from the DCMs, and the consumption schedules of the P2H devices are adapted accordingly.
Complete description
Before the start of the current ISP, Heat Providers determine admissible consumption profile for their Heat Users, and the DCMs determines an optimal aggregated total consumption profile of all active buildings or P2H assets (like Ecovat system) that they have contracted; this can be by either an optimization at the DCM level, or it can be an aggregation of optimal profiles and flexibility determined by the Heat Providers themselves. This information is combined with the safe Flex Capacity Band information from the DSO to determine the available aggregated flexibility per grid zone. Based on this, flexibility offers (products) per balancing group are made and offered to BRPs. Approx. 2' after the start of the current ISP, BRPs receive an imbalance forecast for the current ISP (e.g., an imbalance price forecast) and based on that they determine what flex order to formulate in response to flex offers they received before the start of this ISP for the current ISP from the DCMs. This resulting flex order which represents a delta energy plan for the current ISP is then provided to the DCM who adapts his consumption plan for the current ISP which in turn leads to the adaptation of the consumption plans of Heat Providers and Heat Users.

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Use case conditions
Assumptions
▪ This business Use Case describes a proposed future interaction scheme between energy system participants, requiring a change in their current roles and responsibilities, as well as regulation. ▪ DSOs can determine grid zones and provide a safe Flex Band per grid zone for the next ISP; we assume that the safe Flex Bands do not 'conflict' with the latest earlier provided flex band that lead to a consumption planning in such a flex band for the localRESCurtailmentMitigation and/or SystemRESCurtailmentMitigation business use cases ▪ TSOs provide intra-TSO information that allows BRPs to forecast imbalances for the complete current ISP and based on that take action. ▪ Flex providers can adapt their intra-ISP consumption plan based on an order coming after the start of the ISP.
Prerequisites
▪ The DSO has an up-to-date grid model ▪ The DSO knows what Heat Providers are contracted by which DCMs (this is rather static information): he needs this information to define the Grid Zones for each DCM (if there are multiple), and he needs this to know what forecasts he must make himself versus what forecasts he can expect to receive from which DCM ▪ The DCM knows the Balancing Group (i.e. it is rather static information): they know what Heat Providers are contracted by which BRP. They need this information to know which flex to offer to which BRP.

5.3.2 Diagrams of use case

Diagram(s) of use case
Sequence diagram

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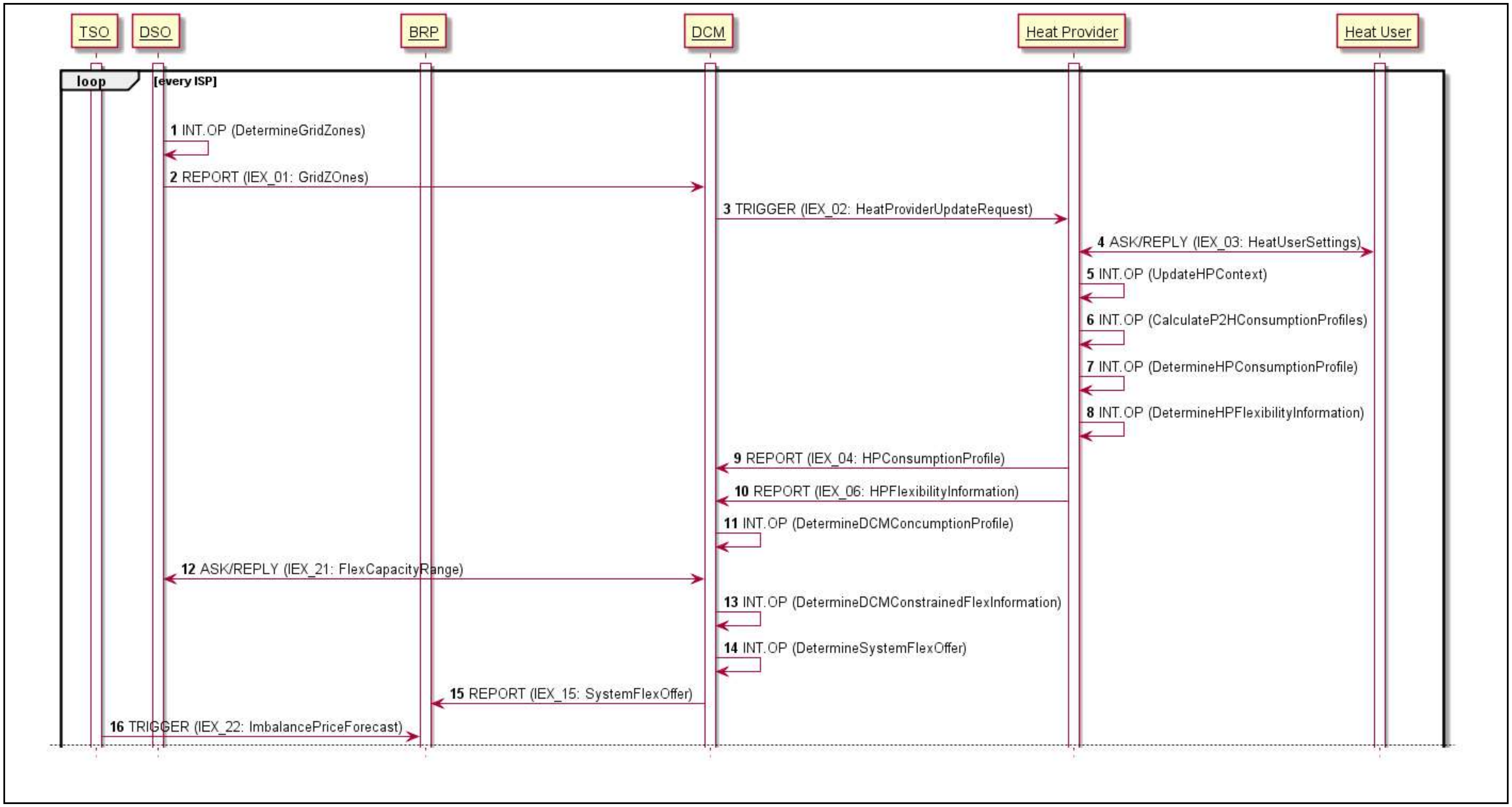

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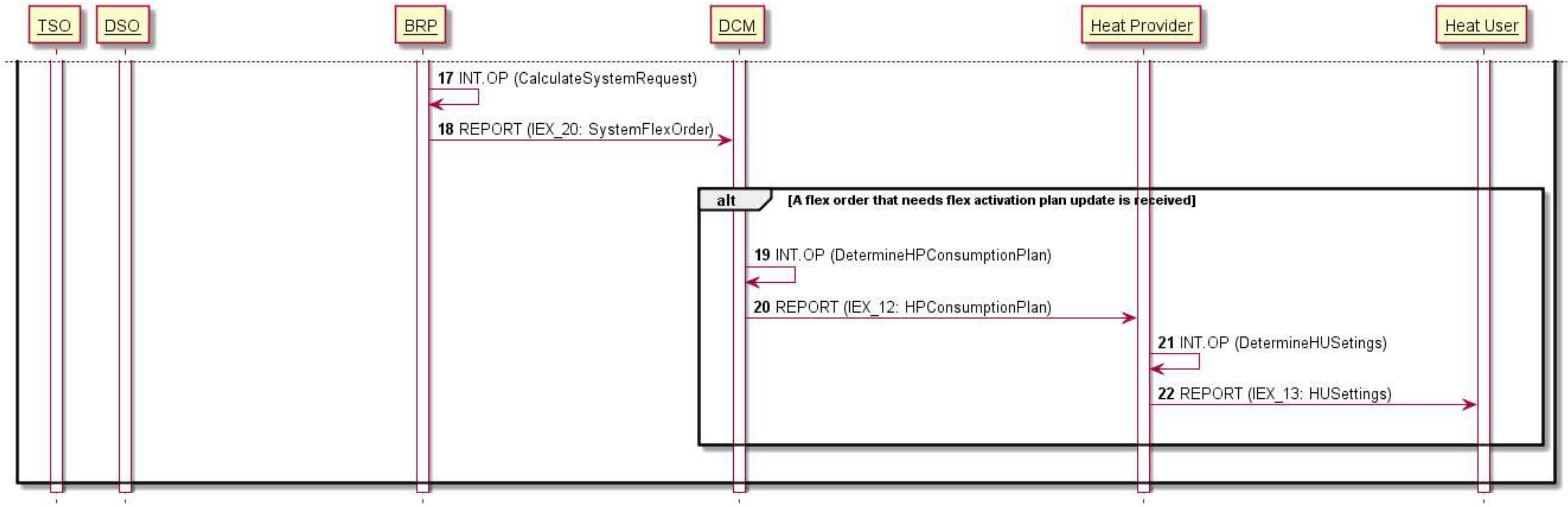

Notes:

- **Steps 1-15 take place in the previous ISP and prepare for the System Flex Order and corresponding flex activation schedule in the current ISP.**
- **Step 16 is the trigger from the TSO to the BRP, informing him (a few minutes in the current ISP) about what the expected imbalance will be.**
- **Step 17-22 take place in the current ISP based on the trigger sent by the TSO, and results in an energy consumption plan update for the current ISP.**

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5.3.3 Step by step analysis of use case

Scenario conditions						
No.	**Scenario name**	**Scenario description**	**Primary beneficiaries**	**Triggering event**	**Pre-condition**	**Post-condition**
1	Normal operation	No exceptions (like no safe Flex Band).	BRP	Time Trigger		

Scenario 1						
Scenario name :	Normal operation					
Step No.	**Name of process/ activity**	**Description of process/ activity**	**Service**	**Information producer (actor)**	**Information receiver (actor)**	**Information exchanged (IDs)**
1	Determine GridZones	Decide which connection points can be clustered	Internal Processing	DSO	DSO	—
2	Send GridZones	Send list of grid zones with associated connection points to each DCM	REPORT	DSO	DCM	IEX_01
3	Send Heat Provider Update Request	Request Heat Providers to provide the latest information	TRIGGER	DCM	Heat Provider	IEX_02
4	Get Heat User Settings	Retrieve actual comfort, temperature and willingness to offer flex information	ASK/REPLY	Heat Provider	Heat User	IEX_03
5	Update Heat Provider Context	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)	Internal Processing	Heat Provider	Heat Provider	—

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6	Calculate P2H Consumption Profiles	Calculate admissible P2H profiles	Internal Processing	Heat Provider	Heat Provider	—
7	Determine Heat Provider Consumption Profile	Select most optimal profile from all calculated ones. (retrieve current one or determine new one, but within the latest agreed flex band constraints !)	Internal Processing	Heat Provider	Heat Provider	—
8	Determine Heat Provider Flexibility Information	Determine flexibility with respect to the optimal baseline consumption profile	Internal Processing	Heat Provider	Heat Provider	—
9	Send Heat Provider Consumption Profile	Send optimal baseline profile	PUT	Heat Provider	DCM	IEX_04
10	Send Heat Provider Flexibility Information	Send flexibility information	PUT	Heat Provider	DCM	IEX_06
11	Determine DCM Consumption Profile	Determine the DCM optimal consumption profile within the latest agreed flex band.	Internal Processing	DCM	DCM	—
12	Get Flex Capacity Range	Ask and receive the flex capacity range that will constrain the balancing flex offers that can be made	ASK/REPLY	DCM	DSO	IEX_21
13	Determine DCM Constrained Flex Information	Determine flexibility with respect to the optimal baseline consumption profile	Internal Processing	DCM	DCM	—
14	Determine System Flex Offer	Calculate Flex Offer(s) for possibly multiple BRPs (using knowledge of balancing groups)	Internal Processing	DCM	DCM	—

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15	Send System Flex Offer	Send System flex offers to BRP	REPORT	DCM	BRP	IEX_15
16	Send Imbalance Price Forecast	Send Imbalance Price Forecast information for the current ISP	TRIGGER	TSO	BRP	IEX_22
17	Calculate System Flex Request	BRP calculates if, how much flex activation would be needed in the current ISP to mitigate system RES curtailment	Internal Processing	BRP	BRP	—
18	Receive System Flex Order	BRP confirms the system flex request with a system flex order (this can be immediately an order; no request needed; by definition what is offered is available and OK for the local grid)	REPORT	BRP	DCM	IEX_20
	IF_1 Flex is ordered					
19	Determine Heat Provider Consumption Plan	Disaggregate the received system OP flex order into a plan per Heat Provider	Internal Processing	DCM	DCM	—
20	Send Heat Provider Consumption Plan	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)	REPORT	DCM	Heat Provider	IEX_12
21	Determine Heat User Settings	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User.	Internal Processing	Heat User	Heat User	—

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		Determine the corresponding P2H setpoints for the Heat User.				
22	Send Heat Users Settings	Update Heat User's P2H setpoints (e.g. control plan for the heat pump)	REPORT	Heat Provider	Heat User	IEX_13
	End IF_1					

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6 Business models

The objective of this task is to specify the business model resulting of the implementation of the defined business cases.

The purpose of the definition of the business model is to assess up to what point each role achieves a real economic benefit derived from the execution of the FHP business use cases in the pilot sites, as the business models reflect interactions that will be certainly demonstrated on the project pilot sites. In order to asses this issue, the e^3value methodology will be used.

6.1 The e3 value methodology

e^3 value is a conceptual modelling approach aimed at facilitating the statement, communication and understanding of the value proposition of an innovative business idea. In addition, it is also designed to allow for a rigorous evaluation of its economic feasibility. As a third goal, it also intends to build the bridge between the expression of the business idea and the identification of the required supporting information systems, in order to avoid the usual thinking of Information and Communication Technology (ICT) as an expense only, rather than as a tool to create value for customers and the company itself.

This approach was created to provide answers to the main challenges of the e-commerce development in the times of the turn of the century and it was thereafter adapted to analyse services for the energy market[84]. Many e-commerce ideas failed because they did not have a sound and clear value proposition. A value proposition must be sound so that each entity involved can make profit or increase its economic utility, and it must be clear because customers hesitate to adopt new products or services if their added value is not obvious or if they are considered to be too complex. In other words, all the stakeholders involved in the business idea must be able to make profit or to increase their economic utility, and all of them must have a common understanding of the value proposition.

Two of the main characteristics of e^3value are that it is a graphical approach and that it focuses on the economic value. Therefore, the representation of the business idea takes the shape of a value model. A value model represents a number of roles who exchange objects of economic value with each other, i.e. it represents what objects of economic value are exchanged by whom, as opposite to process models, which represent how those exchanges are operationally performed. In fact, it represents what is offered to whom and what is requested for it in return (in the economic sense).

The main concepts to express the model are:

- Role: A role is perceived by its environment as an independent economic (and often also legal) entity. A role makes a profit or increases its utility. Economically independent means that it is profitable after a reasonable period of time (when referring to companies) or to increase their economic utility (when referring to end customers). In a sound and sustainable business model each role should be capable of making profit.

[84] This adaptation was made in the EU-EESD-11622 BUSMOD project, http://e3value.few.vu.nl/projects/ourprojects/busmod/

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- Value Activity: Roles perform value activities in order to increase their profit or economic utility. Therefore, the execution of a value activity must yield profit for, at least, one role. In addition, each value activity must be able to be assigned as a whole to a role.
- Value Object: Roles exchange value objects, which are services, products, money, or even consumer experiences. The important point here is that a value object is of value for one or more roles.
- Value Port: A role uses a value port to show to its environment that it wants to provide or request value objects. The concept of ports enables us to abstract away from the internal business processes, and to focus only on how external roles and other components of the business model can be 'plugged in'.
- Value Offering: A value offering models what a role offers or requests from its environment. The closely related concept 'value interface' (see below) models an offering to the role's environment and the reciprocal incoming offering, while the value offering models a set of equally directed value ports exchanging value objects. It is to model e.g., bundling: the situation that some objects are of value only in combination for a role.
- Value Interface: Roles have one or more value interfaces, grouping individual value offerings. A value interface shows the value object a role is willing to exchange in return for another value object via its ports. The exchange of value objects cannot be divided at the level of the value interface.
- Value Exchange: A value exchange is used to connect two value ports with each other. It represents one or more potential trades of value objects between value ports.
- Market Segment: The market segment shows a set of roles that, for all of their value interfaces, give the same economic value to objects.

The concepts above can be used to model value exchanges between roles or market segments, but do not give the idea of which value activities or value exchanges must take place, so that some other value activities or value exchanges can also take place. In other words, they do not represent the order in which value exchanges must take place. To that end, some other concepts are used:

- Scenario path: A scenario path consists of one or more segments related by connection elements and start and stop stimuli. A path indicates via which value interfaces objects of value must be exchanged, as a result of a start stimulus, or as a result of exchanges via other value interfaces.
- Stimulus: A scenario path starts with a start stimulus, which represents a consumer need. The last segment(s) of a scenario path is connected to a stop stimulus. A stop stimulus indicates that the scenario path ends.
- Segment: A scenario path has one or more segments. Segments are used to relate value interfaces with each other (e.g., via connection elements) to show that an exchange on one value interface causes an exchange on another value interface.
- Connection: Connections are used to relate individual segments. Each fork splits a scenario path into two or more sub-paths, while each join collapses sub-paths into a single path. In AND forks/joins, all incoming and outgoing paths have the same number of occurrences, while in OR forks (joins) the number of occurrences of the incoming (outgoing) path equals the addition of the number of occurrences of the outgoing (incoming) sub-paths. An implosion (AND connection with only one incoming and one outgoing port) shows a change in the number of occurrences within a sub-path.

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Table 6 below shows the graphical representation of the main e3value concepts.

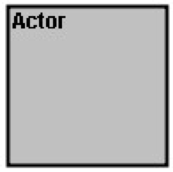
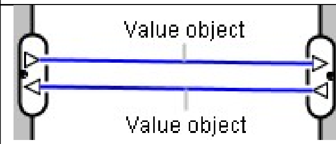
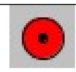
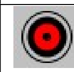
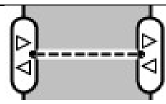
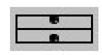
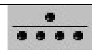
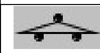
Concept	Graph	Concept	Graph
Role		Market segment	
Value port		Value interface	
Value object		Value exchange	
Start stimulus		End stimulus	
Segment		Implosion	
AND fork/join		OR fork/join	

Table 6: Graphical representation of main e3value concepts.

The goal of the e^{3}value is to evaluate a business idea, and discover a business scenario, which consists of the value model and the scenario path, feasible for every stakeholder. Therefore, e^{3}value assumes that business developers already have a business idea in mind and, thus, it aims at clarifying and evaluating such idea more thoroughly. As a result, e^{3}value is not intended to find business ideas themselves.

In order to create the business scenario, a number of sequentially executed steps are needed. The result of each step is an input for the following step, and the outcome of the whole process is a business model including a graphical representation and corresponding financial profitability sheets, which facilitate sensitivity analysis of the business case. The graphical description of the process of building a business model is illustrated in Figure 30.

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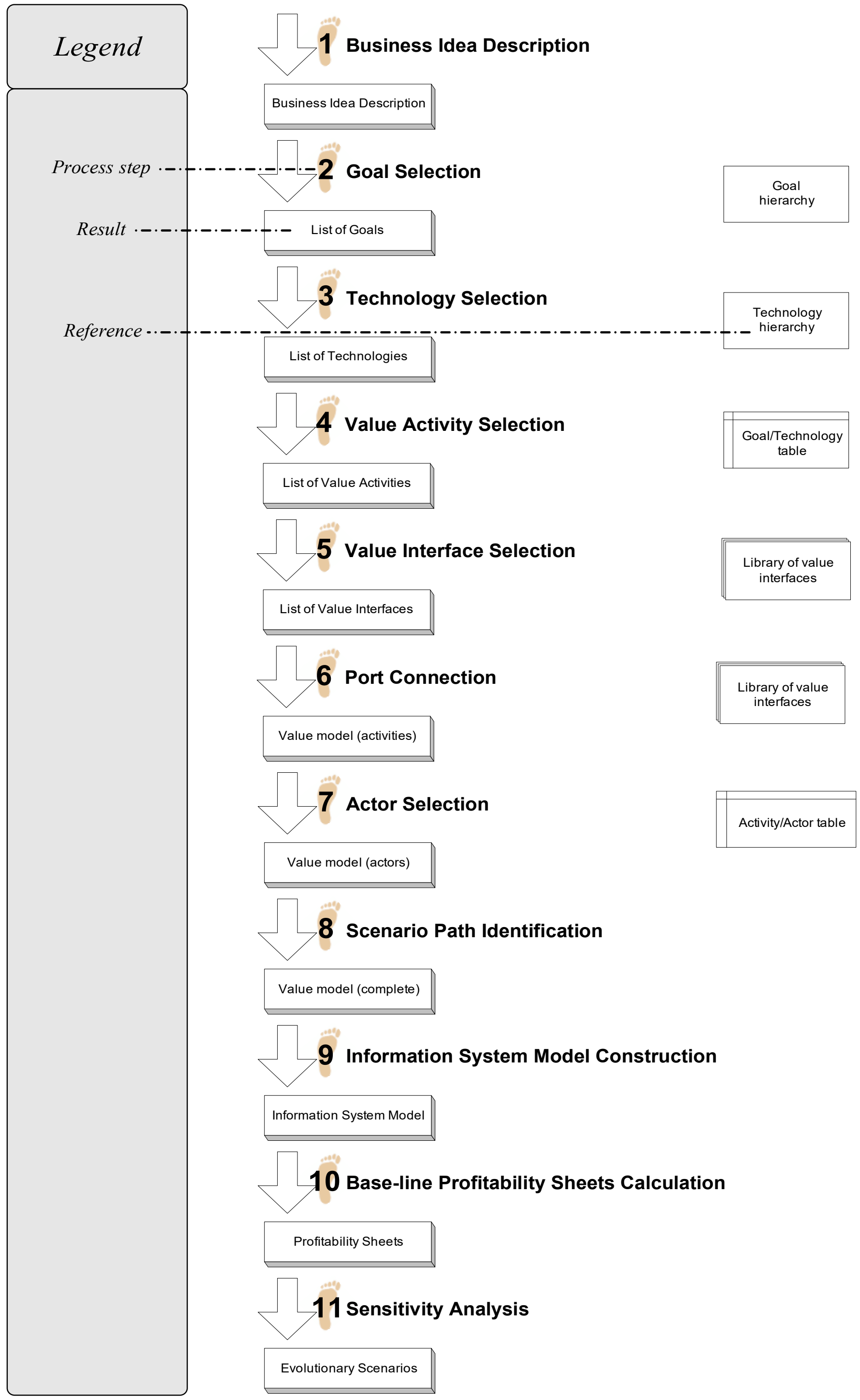

Figure 30: Diagram of the e3value process steps.

1. Step 1 – Business idea description: Write down a short business case description to express the business idea. The value model is a representation of the real world and, hence, such a representation cannot include all objects of the real world. Before the modelling process starts, it is important to consider what needs to be modelled and what not. In addition, a novel business

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idea can only succeed if all involved roles regard it as a profitable idea, so all involved roles should have benefits from the business idea, and the only way to calculate the profitability is to include these roles in the value model. Consequently, the basic rule is to include all involved roles and activities in the value model process.

2. Step 2 – Goal selection: The first consideration to be taken when modelling the business is specifying all the goals stakeholders want to satisfy with that business. Some stakeholders' goals may be in conflict with some others' goals, since every role wants to maximise its profit; but some other stakeholders' goals can also be mutually beneficial. Stakeholders' goals can be strategic (long-term) or operational (short-term).
3. Step 3 – Technology selection: Once the goals are identified, the next step is to select an appropriate technology which will deliver the best output of the scenario and achieve both operational and strategic goals.
4. Step 4 – Value activity selection: In this step, value activities to be included in the model are selected.
5. Step 5 – Value interface selection: In this step, all value interfaces necessary to model the business case are selected from a library of interfaces where general and optional interfaces are provided for each activity. For each selected value activity of the previous step, at least the general interfaces must be modelled. Depending on the scope and the goals to accomplish, the optional interfaces can also be added to the model.
6. Step 6 – Ports connection: Before this step the model is unconnected. The value interfaces now must be connected to obtain a connected value model.
7. Step 7 – Role selection: Each activity should be performed by a role, but this is not a strict one to one relation. Some roles perform more than one activity, and in some cases an activity should be divided over two roles.
8. Step 8 – Scenario path identification: A scenario path is used to explain cause-effect relationships by travelling over paths through a system. By travelling over the scenario path, you can see which role starts exchange and what exchanges are done as a result of this start. Scenario paths allow to count the number of value exchanges in a given time period, which is very important to do profitability analysis.
9. Step 9 – Information system model construction: Once a correct value model has been constructed, the information system needed to support such a model needs to be addressed. This step is performed only when the expenses to maintain such an information system are substantial; otherwise they will be included as operation & maintenance costs.
10. Step 10 – Base-line profitability sheets calculation: The evaluation of a business model focuses on the question whether it is feasible from an economic point of view, and whether a scenario is profitable for each role involved in the value model. The impact of the business model in the different roles is assessed by creating profitability sheets for each role involved, where economic value is assigned to objects delivered and received.
11. Step 11 – Sensitivity analysis: During the execution of a business model, the profitability of each role estimated by using profitability sheets, valuation functions, and scenario occurrences and path probabilities, may change substantially. Since it is not possible to predict the future, especially in the case of innovative business ideas where the business developer cannot rely on historical data, the important result of the analysis is not the numbers on profitability themselves, but the reasons behind them (why the business case proved to be profitable/unprofitable) and

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to do a sensitivity analysis to check the robustness of the results obtained when different assumptions are taken.

12. Step 12 – Investment analysis: After a scenario is chosen, a detailed analysis of financial aspects must be made. There are several standard criteria for investment analysis (e.g., NPV and IRR).

6.2 Relevance for BM and FHP

6.2.1 Description of participants

As described before, the e^3 value methodology considers the whole picture. Therefore, the analysis is not only focused on the roles who want to launch a specific business, but also on all the other roles that can be involved, such as some those of other regulated roles.

Next, the specific roles used in the BM definition and their particular attributes are presented.

6.2.1.1 Heat Users

A heat user pays to the Heat Provider for a heating (or cooling) service which involves the conditioning of certain thermal zones in a building.

6.2.1.2 Heat Providers

A Heat Provider purchases electricity to a retailer to operate its appliances. Some of these appliances are P2H systems that are used to provide a heating service to Heat Users. The consumption of the rest of the appliances is freely determined by the Heat Provider, and in the scope of FHP they are considered uncontrollable loads.

A Heat Provider can respond to incentives offered by an aggregator to modify their baseline consumption. A prerequisite for this interaction is that the aggregation service has already been contracted by the Heat Provider. The modified energy in the consumption profile is paid to the retailer at the same retail price that the baseline consumption.

6.2.1.3 Retailer

For Heat Providers, the retailer supplies electricity at a retail price and grid access. Grid access is usually defined by the power term, and as the FHP flexibility will not affect it, is not reflected in the present business model.

The retailer is represented by a BRP, which receives a certain representation fee because of that, in its relationships with the spot market operators (included in the "other electric regulated roles" market segment for the sake of diagram clarity).

The electricity sold to Heat Providers, and other consumers which are not reflected in the business case, is bought by the BRP, either on the spot energy markets or through bilateral agreements with producers. In the business model, just those bilateral contracts with DER Producers are reflected, being the contracts with central producers out of scope.

The retailer also has to pay for grid access to the TSO, depending on the energy that its portfolio of customers consumes.

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Whenever there is an imbalance in the energy bought by the retailer, the retailer has to compensate to the BRP for it.

6.2.1.4 DER Producers

As defined in FHP, the DER Producer is an electricity producer who feeds renewable electricity directly into the distribution system. As in the case of the retailer, the DER Producer contracts the BRP to represent him in the market. The DER Producer can sell its energy in the market or directly to retailers through bilateral contracts.

The DER Producer is also obliged, as the retailer, to the payment of T&D fees to the TSO and imbalance penalties to the BRP.

DER Producer receives from the government (included in "other electric regulated roles"), a subsidy depending on their real production, due to its renewable character.

There are two external circumstances in which the DER Producer cannot fulfil its aim of producing energy, due to grid constraints violations (grid curtailment) or due to the market restrictions (commercial curtailment).

6.2.1.5 DSO

The role of the DSO in FHP is just responsible for guaranteeing local grid constraints, minimizing local DER Producer grid curtailment by means of flexibility negotiation with aggregators.

6.2.1.6 BRP

The BRP is responsible for representing the DER Producers and retailers in the process of energy sale/purchase. On behalf of the retailer, the BRP has the obligation to find the most convenient way to buy the needed energy, either in the market or in a bilateral contract with a DER Producer. In the FHP scope, we tackle the problem that appears in distorted market structures that could prevent DER Producers to sell their production in the market. Under those circumstances, nation-wide consumption is fully covered and the DER Producer would be commercially curtailed, therefore the proposed way to accommodate RES Production is negotiating flexibility with aggregators.

The BRP has to pay to the DSO for imbalances in its portfolio, as it is responsible for imbalances it causes in the system. Usually this payment is partially forwarded to those retailers and DER Producers originating the imbalances, depending on the contract clauses between these parties that regulate the imbalance risk, but the BRP can also try to manage internally its portfolio buying operation phase flexibility to aggregators.

6.2.1.7 Aggregator

The aggregator has a contract with certain Heat Providers, in which the aggregator commits to manage their flexibility consumption. The aggregator receives a fee for that service, despite flexibility is provided or not, and it is usually included there the amortization of the cost of the software / hardware infrastructure installed at the Heat Provider's side.

The aggregator provides negotiation phase flexibility to either the DSO or BRP, and in the operation phase it provides a balancing service to the BRP. These different shapes of flexibility are always based on the free Heat Provider's response to the incentives offered by the aggregator.

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6.2.1.8 Other electric regulated roles

In order to simplify the analysis, several regulated roles in the electricity system have been represented graphically as a single role since the results to be obtained within FHP analysis are not focused on the profitability of such roles.

The entities considered in this pooling are:

- The TSO which receives the T&D fees from DER Producers and retailers and payments from the BRPS due to imbalances
- The government which pays to DER Producers due to its renewable production (as kind of feed-in tariffs, etc.)
- The Market Operator which matches the production (sale) bids with the requested consumption (purchase) bids

6.2.2 Graphical representation of the business model

This section presents the graphical representation of the BM which has been used as a basis for the specification of the cost-benefit analysis and the explanation of the model.

Although the market arrangement and conditions can slightly differ from Sweden to the Netherlands, the model resulting for this analysis has been simplified in order to present a general case suitable to be deployed in any country.

When assessing the implementation of the selected sub-functionalities, it can be stated that there are five paths of money flows in this model: one for the non-flexible electricity supply and another one, in which flexibility is provided, resulting from each of the FHP business cases.

6.2.2.1 Non-flexible electricity path

It is composed of the following steps which can be followed in the graphical model.

Step 1 (Red start stimulus and red exchange)

Each heat user receives a heating service provided by its contracted Heat Provider. The objective of the heating service is to condition the thermal zones in charge of the Heat Users, being each thermal zone each room or appliance which temperature setpoint can be controlled independently. The contract between the heat user and Heat Provider reflects the references used for billing the service as well as the clauses that govern the obligation and rights of both roles.

The Heat Provider operates a P2H system to provide the heating service to one or more Heat Users, and the implosion symbol used at the Heat Provider graphical representation models the conversion from electricity (dark blue exchange) to the heating service (red exchange).

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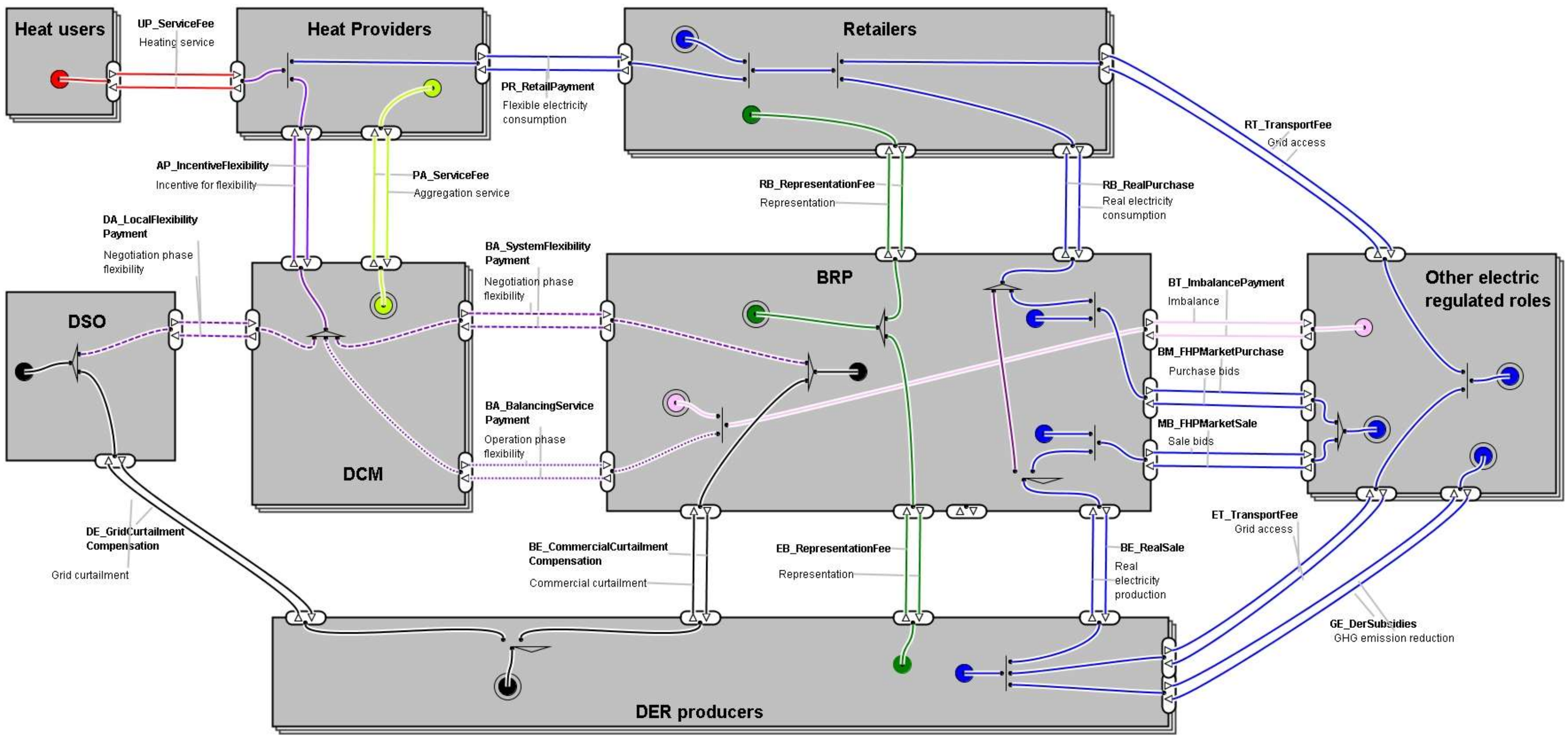

Figure 31: FHP BM graphical representation.

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Step 2 (Dark blue start stimuli and exchanges)

The Heat Provider has the responsibility to estimate and calculate the operation schedule of each P2H system which fits the conditions of the heating service agreed with the heat user, so that the heat user is always inside its comfort zone. This outcome can be achieved through different operation schedules, and the criteria used by the Heat Provider is always to select the schedule that minimizes the operation cost associated to the electricity expenditures. In this non-flexible electricity path the Heat Provider calculates the baseline electricity consumption of the collection of P2H systems that it operates, which is the electricity consumption when no flexibility is promoted by the aggregator. The electricity used to operate the P2H system based on the baseline P2H schedule is added (AND symbol) to the electricity used for running the other non-controllable loads of the Heat Provider. This baseline electricity consumption is bought to the retailer and paid at the agreed retail price.

The retailer aggregates all the consumption of its consumers (for simplicity we do not represent in the graphic other consumer than Heat Providers). In this value path, just the baseline consumption of Heat Providers is not void (AND in the “retailer box”), and these incomes represent the only money source of the retailer. The retailer is a non-regulated role which pursues and economic benefit, so taking into account its intended profitability margin it has to calculate the retail prices depending on its costs. This profitability margin is depicted as the dark blue stimulus in the Retailer graphical representation.

The costs of the retailer depend on these value exchanges:

- Purchase of electricity: To cover the consumption of Heat Providers, a retailer could buy the energy either at the spot markets or through bilateral agreements with producers. Due to the public nature of historic market prices we will consider in the FHP analysis that all the electricity bought by the retailer in this non-flexible path is bought at the market.
- Transmission and distribution fees: Retailers, on behalf of consumers, buy grid access from the DSO, because the retailer has to pay to the regulated system operators for the utilization of the grid infrastructure depending on the consumption of its consumers. With that purpose, the retailer collects the T&D fees from consumers, which are included in retail electricity price that the Heat Provider pays (AND3 decomposition at the retailer box). We just consider the fees associated to energy consumed (kWh), and not the contracted power, as the FHP objective is to modify the consumption patterns in renewable surplus situations and this will have no reflection in the contracted power of each Heat Provider. The sink of this payments uses to be the DSO stakeholder, and the DSO will redistribute this payment to the TSO. This exchange is directed to the “other electric regulated roles” because this responsibility of the DSO is not part of the FHP DSO role.
- BRP representation fee: Described in step 3
- Payment for imbalances: Described in step 4

Analogously to the retailer, the DER Producer also has a relationship with the BRP and the DSO. The DER Producer produces energy depending on its abilities (dark blue stimulus), and the government pays an incentive depending on that production based on the associated Greenhouse Gas (GHG) emissions reduction. Apart from that income, the DER Producer has to pay to the DSO for the T&D fees (AND2) and sell its production (through the BRP) at the market. The BRP representation fee (step 3) and the payment for imbalances are also applicable (step 4).

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The market operator is the role responsible for matchmaking the sale and purchase bids presented by the BRP on behalf of its DER Producers and retailers. These exchanges are represented towards the “other electric regulated roles”, end conclude in a dark blue end stimulus which represents the market matching process.

Step 3 (Dark green exchanges and stimuli)

Retailers and DER Producers do not either buy or sell energy directly, as the BRP is the role which intermediates to do the energy trading on behalf of both. Consequently, the BRP receives a representation fee for that service.

Step 4 (Pink exchanges and stimuli)

The TSO is responsible for maintaining the system balance (pink start stimulus at the (other electric regulated roles” box) and these costs are forwarded to the BRPs which have been out of balance. Typically, only the BRPs which have deviated in the same direction of the imbalance are penalized, while those BRPs which have compensated the imbalance are not. Imbalance prices are in general provided by the TSO after the provision of the regulation services has concluded for each imbalance settlement period (ISP). The BRP forwards these costs (AND element) to its retailer and DER Producers which have had deviations, usually adding an internal profitability margin (pink end stimulus). In which conditions and to what cost does the BRP forward this costs to retailers and DER Producers is represented by the pink exchanges that represent the payment for imbalances of these roles.

Step 4 (Black exchanges and stimuli)

If the BRP cannot allocate the production of a DER Producer either at the market or through a bilateral agreement (black start stimulus at the BRP box), the DER Producer has to be stopped. We refer to this circumstance as commercial curtailment.

If it is the DSO the role which prevents the DER Producer from producing due to local grid constraints (black start stimulus at the DSO box), we refer to grid curtailment.

In both situations, the DSO or the BRP have to compensate to the DER Producer for being curtailed.

6.2.2.2 Flexible electricity path

This path represents the value proposition of the FHP project, where P2H flexibility is used to address four different business use cases.

- localRESCurtailmentMitigation: The DSO uses operation phase flexibility to avoid grid curtailment
- SystemRESCurtailmentMitigation: The BRP uses operation phase flexibility to avoid commercial curtailment
- balancingServices: Heat Providers help to the BRP to actively balance its portfolio

The value exchanges associated to this flexible path are divided in the following steps:

Step 1 (Light green exchanges and stimuli)

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The aggregator is the role which enables the provision of flexibility by the Heat Providers. Generally, it provides the infrastructure and the intelligence that Heat Providers need to be able to sell their flexibility. But not limited to that, the tools installed by the aggregator on the Heat Provider side can also be of high added value to understand and optimize the P2H systems operation. Therefore, Heat Providers pay to the aggregators for the deployment of the infrastructure and the service by means of an aggregation service fee.

Step 2 (Solid magenta exchanges)

The aggregator markets flexibility in any of the three different business cases (as described in steps 3 and 4). In order to enable this marketization, the aggregator offers an incentive to each Heat Provider and in consequence, the Heat Provider can modify its baseline schedule for operating some of its P2H systems (magenta exchange towards the implosion symbol). The modifications in the schedule imply a variation in the electricity consumption of the Heat Provider, which are paid (or saved) at the retail price to the retailer.

The variations in the consumption of the Heat Providers due to the delivery of flexibility are therefore transparent to the retailer. These consumption variations could either be allocated by the BRP at the market or through bilateral contracts with DER Producers (OR element at the BRP’s box).

Step 3 (Slashed magenta exchanges)

The aggregator can sell flexibility either to the DSO or to the BRP at the flexibility negotiation phase. The DSO can order flexibility to avoid local DER Producers’ curtailment due to grid constraints (localRESCurtailmentMitigation business use case) and the BRP would order flexibility to increase consumption to avoid commercial curtailment in those market situations in which it could not allocate the production of some DERs in its portfolio (systemRESCurtailmentMitigation business use case).

Step 4 (Dotted magenta exchanges)

Operation phase flexibility can be ordered by the BRP to minimize its internal imbalance (AND1 element at the BRP’s box), trying to actively act on its internal imbalance position (BalancingService business use case)

6.3 Quantitative analysis

The performance of a detailed economic analysis would allow the economic impact assessment of this FHP BM on each role involved. It needs to consider; (i) the relationships between roles which must be taken into account, (ii) the formulas that need to be used and (iii) data that need to be collected for making these calculations. Based on the graphical model created through the e^3 value tool, the annual flows of funds for all the roles involved can be calculated. These flows would then be used as an input to calculate each role´s annual cash flow. Once the annual cash flows are obtained, the last step would be to check the profitability of the investments the different roles need to perform.

Many of the data and financial parameters to be used in these calculations are difficult to estimate. Since the installations of the required infrastructure for the FHP BM deployment can take several years and the needed regulatory changes promoted by the Winter Package [23] are expected to come into force from 2020 – 2025 onward, this quantitative analysis will be based only in the first two steps indicated above in order to avoid the inclusion of the inherent uncertainty of long-term data forecast.

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Consequently, this analysis will only identify the mentioned relationships and the formulas to be applied. As a last step, several boundary conditions (minimum set of economic parameters) will be analysed in order to establish which issues may strengthen or threaten this business model.

The relationships between actors and the related economic interactions to be established for the development of the FHP BM are shown in section 6.3.1. The mathematical expression of the value objects exchanged is detailed in section 6.3.2.

6.3.1 Relationships between participants

Based on the graphical model, the involved roles in the BM and the relationships between them can be easily established. Some flows of funds belong to the "non-flexible electricity path", which does not depend on the business model under analysis, but strongly depends on the existing market, regulation and legal arrangements in each specific country.

Table 7 presents the relationships between the different roles in the FHP BM. Each cell presents the object that the role in the row pays to the row in the column. For example, Heat Providers pay for Electricity consumption to the Retailers.

to pays for	DER Producer	Heat User	Heat Provider	Retailer	Aggregator	DSO	BRP	Other roles
DER Producer							Representation Imbalance	Grid access
Heat User			Heating service					
Heat Provider				Electricity consumption	Aggregation service			
Retailer							Representation Imbalance Electricity consumption	Grid access
Aggregator			Consumption flexibility					
DSO	Grid curtailment				Negotiation phase flexibility Operation phase flexibility			
BRP	Commercial curtailment Electricity production				Negotiation phase flexibility Operation phase flexibility			Purchase bids Imbalance
Other roles	GHG emission reduction						Sale bids Imbalance	

Table 7: Relationships between roles in the FHP Business Model.

Based on these relationships, the periodic flows of funds for each actor are obtained by adding all the items in their column and subtracting all the terms in their respective row. For example, the cash-flow for the Heat Provider in this BM will be:

$$CF_{HP} = Heating\ service - Electricity\ consumption - Aggregation\ service$$

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6.3.2 Exchange formulation

Hereafter the formulation of each value exchanged between roles is provided. These objects will be used for the definition of the cash flows in the following section.

6.3.2.1 Heating service

The transaction between the Heat User and the Heat Provider is based on the exchange of money for the provision of a heating service.

The climatic services of enclosed spaces for human use are one of the sectors which can be favoured from the incentives that arise around the flexible consumption of energy. The normal operation for these climatic systems based on P2H systems has consisted so far in establishing a setpoint operating temperature, *T_Comfort*, which was considered indeed to be the temperature that maximized the comfort of the people who used that space. The Heat Provider takes care of the P2H system in order to maintain a typical constant curve of temperature which is the temperature that gives the Heat User occasion to maintain a proper level of comfort.

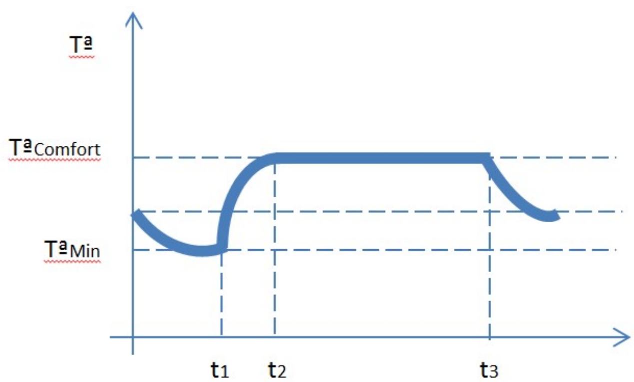

Figure 32: Ideal temperature to maximize comfort.

Thus, if a variation of temperature occurs, it is assumed generally that there could be a negative loss of comfort:

$$\left|\frac{\partial Comfort}{\partial T^{\circ}}\right|$$

A way to compensate the reduction of comfort with temperature could be by means of the addition of a new term which could compensate this negative variation, as it could be for example the case when the variation on temperature is compensated through an economic term.

$$\frac{\partial Comfort}{\partial €}$$

If the comfort added by the received money is above the loss of comfort, which depends on temperature, the user does not mind to tolerate the induced variation in temperature.

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$$\frac{\partial Comfort}{\partial €} - \frac{\partial Comfort}{\partial T°} > 0$$

The economical term substitutes then the ideal *T_Comfort* by the temperature range in which this equation complies.

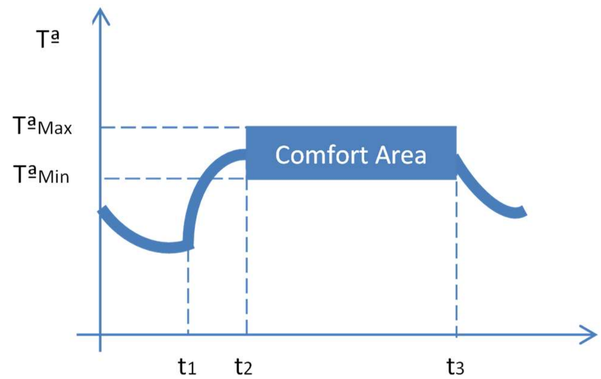

Figure 33: Comfort area.

This theoretical approach was tested in previous research projects, like Wattalyst (FP7, grant agreement 2888322). The conclusion of the Wattalyst tests to validate the goodness of the provision of economic incentives to stimulate discomfort[85], was that in commercial environments users do not react to monetary incentives as expected. Alternatively, the environmental awareness proved to be the most recommendable catalyst to promote that the users agree on permitting the operation of the HVAC within a predefined temperature range. In this way, the chances to operate the P2H system in a flexible way are highly increased.

Therefore, the case presented in this document is based on a business model in which the Heat User does not receive any economic incentive for the modification of *T_Comfort*. The flexible operation of the P2H, has not an effect on the monthly bill paid by the Heat User due to the heating service received, but it affects the profit obtained by the Heat Provider due to the variation of the consumption profile and its associated costs. The Heat Provider is responsible for the selection of the plan to operate the P2H system, which will always guarantee that the Heat User will be inside its comfort area.

The Heat User does not receive then any monetary incentive at the time that its *T_Comfort* is modified, but it should receive a reward based on the reconnaissance of its participation in flexibility provision. As the Heat User awareness is based on the value of enhancing the utilization of renewable energies, it should be informed of the fact that he is currently supporting that renewables are not curtailed.

In the classical operation of a P2H system, it begins providing thermal power at its nominal rate, *Pmax*, in time instant t1 such that the temperature reached in t2 is the temperature required by the final user, *T_Comfort*. The P2H operation between t2 y t3 intends to maintain *T_Comfort*, while the thermal power provided decreases continuously. The power consumed during this period shows a high

[85] Deliverable D6.2, Field Trial Conclusions

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consumption in t1 in order to increase the temperature lost at night and afterwards a consumption that has to deal exclusively with thermal loses. And finally, between t2 and t3 the P2H is disconnected until the next day, while the thermal zone does not need to be conditioned because of user behaviour requirements (for instance, out of office hours),

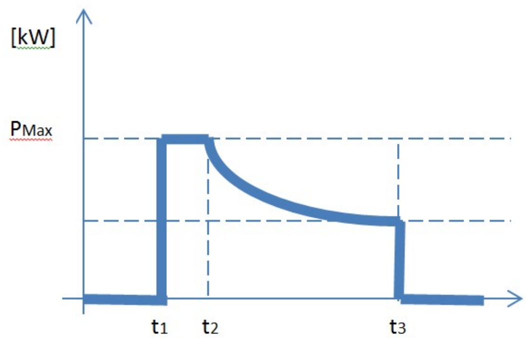

Figure 34: Power consumed to maintain the temperature in the comfort range.

If the temperature is maintained between the temperature comfort range instead of being always *T_Comfort*, the Heat Provider could operate the P2H taking advantage of the benefits arising from providing flexibility to the aggregator.

In those cases, it could occur that the Heat Provider receives a request from the aggregator either to increase or to decrease its consumption over the baseline. In the figure below, the aggregator asks to the Heat Provider to increase its consumption between tx and ty and to decrease it between ty and tz (both of them over the baseline consumption which is required to maintain *T_Comfort*). As it can be seen, the energy consumed during the overconsumption period is cheaper than the typical price of energy and the energy not consumed during the consumption periods is paid by the aggregator to the Heat Provider.

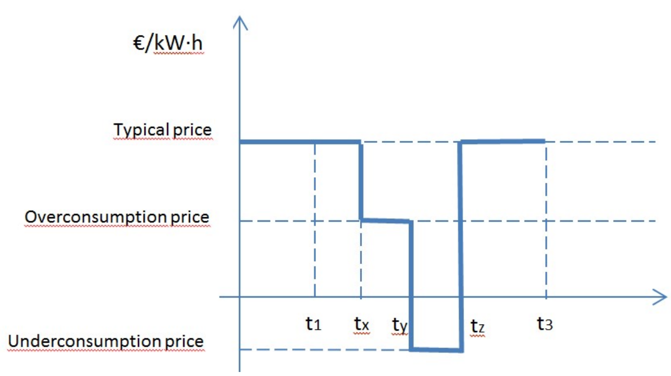

Figure 35: Price for energy based on the markets of flexibility.

The profit obtained by the Heat Provider on this transaction with the aggregator is the grey area of the figure below:

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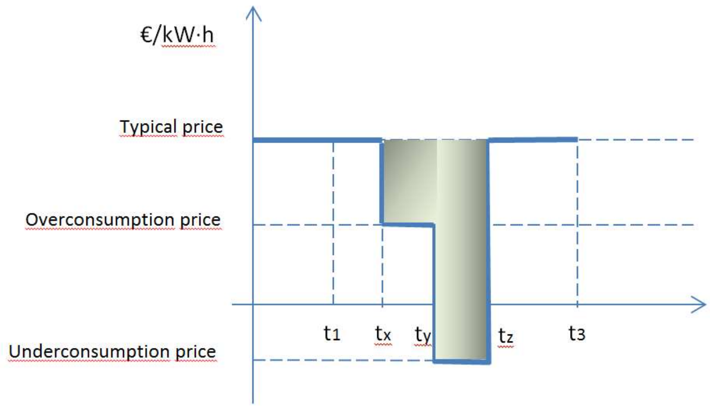

Figure 36: Benefit obtained for the Heat Provider.

If the Heat Provider takes advantage of this opportunity in order to consume more energy between tx and ty and afterwards disconnect the P2H between ty and tz, the new temperature of the room will be as follows:

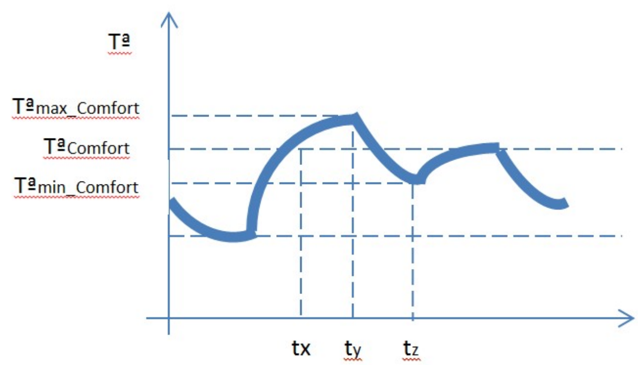

Figure 37: Variation on temperature based on a flexible regulation.

This temperature must be always within the Comfort area. The new consumption of power is more or less as shown in next figure:

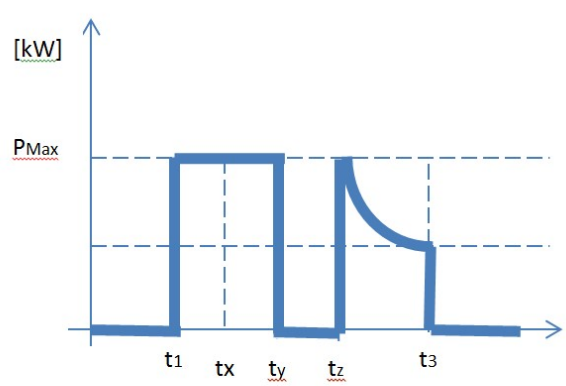

Figure 38: Power consumed under flexible operation.

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There are three aspects that have to be considered when the transaction between the Heat Provider and the Heat User is analysed:

1. The Heat User invoice should not be higher than in the business as usual approach, since it has always the alternative to contract again the traditional service in which the temperature is constantly fixed.
2. The optimization on the Heat Provider side is not energy efficient, it is economic efficient. The economic operation of the P2H system by the Heat Provider could make that the consumption of energy will increase. If the business model for the Heat User would be based in a one in which the monthly payment would depends on the energy consumed, it could occur that at the time that the Heat Provider gets a profit from the aggregator for the operation of the P2H, the Heat User would have to increase its cost indeed of reducing its comfort. The economical operation of the P2H must never imply an increase in the Heat User Invoice. The figure below shows the power consumption when a constant temperature or a variable one is targeted. If the area enclosed by the latter is higher than the area enclosed by the former, the overconsumption of energy would occur.

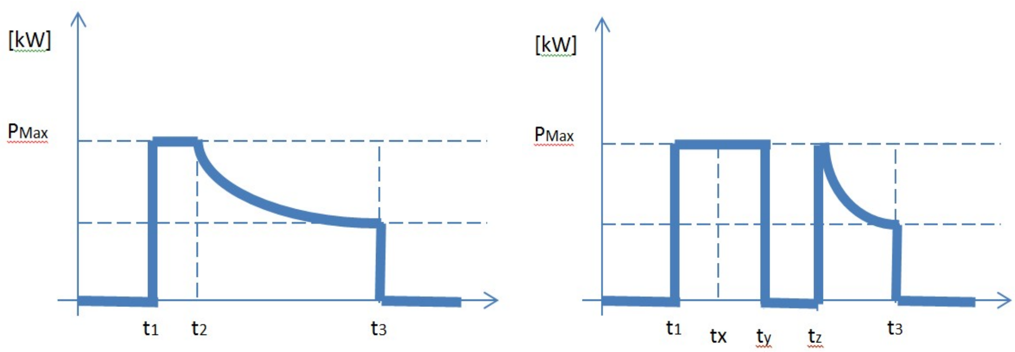

Figure 39: Typical power and power consumed with flexible operation.

3. Another problematic question that has to be solved on the Heat User – Heat Provider transaction is that related with the deviation on the consumption in relation with the expected one. Since the Heat User must be capable to always override the planned operation of the Heat Provider (as a requirement of the Heating Service contract) in order to accommodate the temperature in real time to its real requirements, the incentive offered by the aggregator to the Heat Provider would not be obtained. If the Heat Provider responded to the Aggregator with an under consumption for ty, but the Heat User overrides the P2H to increase temperature, the Heat Provider will not obtain the incentive offered by the aggregator. Therefore, a penalty should be forwarded to the Heat User, maybe only when it occurs so often than the business model risks its profitability. If this behaviour becomes repetitive, it could put an end to the whole business model and completely cancel out the flexibility capacity of the P2H.

A contract should be established between these two roles, in which the following terms have to be agreed:

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- The indoor temperature setpoint range in which the Heat Provider can operate the P2H system. The operation of the P2H system within this temperature range guarantees that the Heat User is always in its comfort zone. It is going to be considered hereinafter that the Heat Provider has the possibility to regulate room temperature within two limits so that the comfort is not reduced (between 19 °C and 22 °C, for example).
- The faculty of the Heat User to override the room temperature setpoint commanded by the Heat Provider.
- The financial consequences in case of override, as the possibility of the Heat User to override the temperature could cause a loss of profit by the Heat Provider, some penalty term should be added in order to take it into account.
- The references used for the billing. It should be related to the heating service conditions (duration of the conditioned period, room surface, level of temperature setpoint, etc.), instead to the electrical energy consumed or to the thermal energy provided. The amount of money which the Heat User has to pay for the heating service would be based on a fix rate, which is expressed by the term Hourly Service Fee.

Heat Users would prefer to pay exclusively with a flat rate, independently of the energy consumed. The contract would be quite long term because the Heat Provider needs to guarantee that it will amortize the investment. Some of the cost that should be included in this monthly bill and which will be called P_{Fix} hereinafter are the following:

- Maintenance costs,
- Personnel costs,
- Amortization.

There must be also in the transaction a term that has to comply with the deviations on the consumption due to override capacity available at the Heat User side. This term should be a function of the energy surplus that the Heat Provider, Energy Overridden, has to face in case of override. There should be an agreement of the price to which the Heat Provider would bill this energy, Override price.

$$Service\ fee_y = \sum_{h=1}^{8760} Hourly\ service\ fee + (Override\ price * Energy\ overriden_y)$$

6.3.2.2 Consumption flexibility

The Heat Provider transacts not just with the Heat User and the Retailer, but also with the Aggregator. This transaction takes opportunity from the flexibility markets: Due to technical or economic factors, there could be provided an additive incentive to the retail price paid by the Heat Provider to the retailer, attractive enough to modify consumption.

This incentive is passed from the Aggregator to the Heat Provider. This incentive appears due to the flexibility requested by the DSO and BRP roles. This incentive is called '*incentive for flexibility*' in the transaction of these particular two roles.

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The Aggregator has a portfolio of Heat Providers to which offer the possibility to modify its baseline consumption (either to increase or to decrease). The Heat Provider can receive from the Aggregator an incentive, either positive or negative, for certain time steps. This incentive is applicable only to the modified consumption compared to the baseline, so it is just paid for the increased or decreased energy compared to the baseline previously communicated by the Heat Provider to the Aggregator.

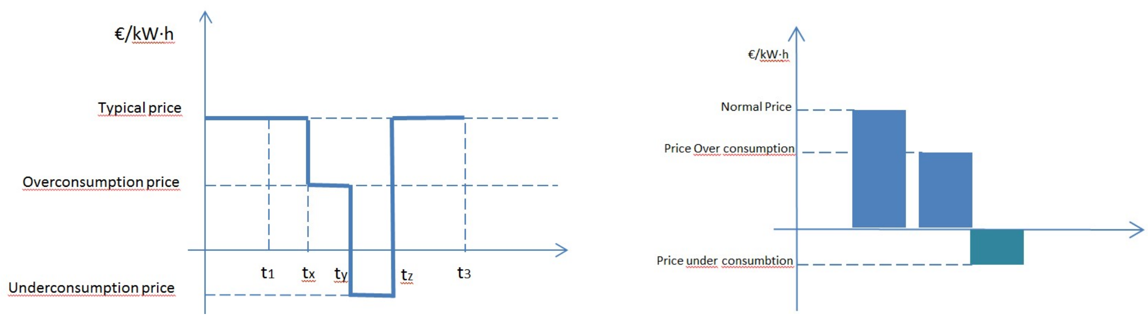

Figure 40: Variable price for energy.

In response to the incentive offer, the Heat Provider must communicate explicitly afterwards to the aggregator if it accepts it or not, and in affirmative case which will be its new expected consumption.

The flexibility provided would then be paid by the aggregator depending on a relative incentive: The aggregator offers to the Heat Provider an incentive (c€/kWh) for increasing/decreasing consumption (compared to its baseline) in certain time steps.

Alternatively, it could be based on an absolute incentive, in which case the settlement would be done for the whole energy consumed by the Heat Provider (not just for its flexibility).

The main constraint in this transaction could be the deviation over the consumption of energy previously estimated. The deviations in this case can occur for instance because of Heat User overrides, because of inaccuracies on the Heat Provider's P2H/building model, variations in the external context. Anyway, it is considered that the response of the Heat Provider is not binding, so no penalty would be imposed by the Aggregator if the real consumption of the Heat Provider deviates from the expected consumption.

Therefore, the formulation of the incentive would be the following, depending on if relative or absolute incentives are applied:

$$Incentive\ for\ flexibility_y = \sum_{h=1}^{8760} Relative\ Incentive_y * Flexible\ electricity\ consumption_h$$

or

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$$Incentive\ for\ flexibility_y = \sum_{h=1}^{8760} Absolute\ Incentive_y * (Flexible\ electricity\ consumption + Baseline\ electricity\ consumption)_h$$

6.3.2.3 Aggregation service

In addition to that the Heat Provider should pay for the *Aggregation Service* an *Annual Subscription fee*. As the aggregator would install on the Heat Provider side some hardware/software that would calculate the baseline and the flexibility capabilities of the Heat Provider. This functionality would help to the Heat Provider to understand better how it consumes energy and will be an inherent benefit to the Heat Provider. Therefore, the Heat Provider would pay a certain fee (€/month) for this service, independently from the fact that it provides flexibility or not.

$$Annual\ subscription\ fee_y = \sum_{m=1}^{12} Monthly\ subscription\ fee_m$$

6.3.2.4 Baseline and flexible electricity consumption

The electricity consumed by the Heat Provider would be paid at the retail price agreed by both parties. This price is fix, so that both parties know it before consumption occurs. But it should be revised periodically, to adapt it to the last prices of the spot markets. The revision period uses to be annual. Different prices could be adopted for the different times of day or for different day types, based on the assumption of the dynamic tariff scheme (Time of Use).

In reality, there is no way that the retailer can distinguish the electricity paid by the Baseline electricity consumption or the Flexible electricity consumption exchange. The separation of the electricity consumption in these two exchanges is just an artefact that we use to be able to calculate the money flows both in the non-flexible electricity path and in the flexible electricity path. That is the reason why these two exchanges are merged in the AND1 operator once they get into the retailer box.

In fact, in the field there will be no way to measure the baseline, as the baseline is the estimation of how much electricity would have consumed the Heat Provider if no flexibility has been provided. We would use then the baseline calculated by the Heat Provider for the settlement of the baseline electricity consumption.

And the flexible electricity consumption will be either positive, if the consumption is increased, or negative, if it is decreased, as it is really an addition to the baseline.

In order to be comparable, the results of the flow cash calculations in both non-flexible and flexible paths, the data sources used for the settlement should be identical, so we propose to use always for settlement the result of the forecasting algorithm of the Heat Provider avoiding the utilization of the

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meter readings of the whole Heat Provider, because we would have no way to infer from there the consumption of the P2H systems.

$$Retail\ price_y = \sum_{h=1}^{8760} Hourly\ retail\ price_y * (Flexible\ electricity\ consumption + Baseline\ electricity\ consumption)_h$$

6.3.2.5 Payment for imbalance (Retailer)

The retailer has to pay to the BRP for the deviations from the expected consumption used for the energy purchase to the real consumption of its portfolio of consumers.

$$Payment\ for\ imbalance_y = \sum_{h=1}^{8760} Hourly\ imbalance\ price_h * Imbalance_h$$

6.3.2.6 Representation (Retailer)

The retailer is not qualified by the market operator to buy the energy directly from the market, so it has to pay to the BRP for that service. The BRP has the commitment to provide all the energy that its retailer would consume, so it has to provide to the BRP that estimation which is the reference for the amount of energy to purchase. The BRP can alternatively buy the energy directly from a DER Producer.

$$Annual\ representation\ fee_y = \sum_{d=1}^{365} Daily\ representation\ fee_d$$

6.3.2.7 Bilateral and market electricity consumption

This exchange is referred to the energy that the retailer buys (through the BRP) to satisfy the expected consumption of its Heat Providers. For simplicity, we assume that the retailer buys all the baseline energy at the market, so the price that it pays for the energy is the market price decided by the market operator at the market clearance. If additional energy is needed due to increased consumption in UC1 or UC2, then there will be a bilateral contract between the retailer and a DER Producer to accommodate the RES production. In that case, the increase of consumption of the Heat Providers due to the flexibility promoted by the aggregators will be directly bough to the DER Producers. However, we will assume that the bilateral price of this transaction will be identical to the respective market price, so that both the retailer and the DER Producer will have no additional gain for establishing this peer to peer contract compared to the market based exchange. Therefore, the formulation of these exchanges would be the following:

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$$Market\ payment_y = \sum_{h=1}^{8760} Hourly\ market\ price_y * Market\ electricity\ consumption_h$$

And

$$Bilateral\ payment_y = \sum_{h=1}^{8760} Hourly\ market\ price_y * Bilateral\ electricity\ consumption_h = \sum_{h=1}^{8760} Hourly\ market\ price_y * RE\_IncreasedElectricityConsumption$$

Where the increase electricity consumption comes from UC1 and UC2.

6.3.2.8 Grid access (Retailer)

In general, in the EU Member States, the electricity supply is made up of the cost of electricity generation, the cost of electricity transmission and distribution and other costs of the electricity system and taxes. Although in some countries, the consumer may receive different bills from the retailer and from the DSO, in most of the cases the retailer sells electricity to consumers and pays for T&D fees to the DSO.

Generally, the T&D fees include two terms, one linked to the contracted power and another term linked to the actual consumption. In the case of this business model, as commented before, we discard the influence of the power term because the flexibility managed by the P2H systems will not affect the monetary transactions influenced by the power term.

Then, the T&D fees depend exclusively on the energy term price, which can be different in different times of the day, and the energy demanded.

$$T\&D\ Fee_y = \sum_{h=1}^{8760} T\&D\ Energy\ term\ price_h * Energy\ demand_h$$

The T&D fees include several concepts that must cover certain activities such as; (i) transmission, (ii) distribution, (iii) retribution to the DSOs for the commercial management of the customers (billing, metering, T&D fees billing, etc.), (iv) retribution to renewable, cogeneration and waste production, (v) diversity and security of supply, and (vi) others[86].

[86] Permanent system costs, deficit from previous years, etc.

In Spain, from 2016, several concepts included until then in the T&D fees have been excluded and now they are included in the term "other costs" within the electricity cost term: Interruptible load service + retribution to the Market Operator (MO) + retribution to the System Operator (SO) + capacity payments.

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6.3.2.9 Imbalance (BRP)

The TSO is the role responsible for the system balance, contracting the necessary resources in the balancing markets to compensate the imbalances introduced by the BRPs. These imbalances are settled at the imbalance price calculated by the TSO.

$$Imbalance\ price_y = \sum_{h=1}^{8760} Hourly\ imbalance\ price_h * Imbalance_h$$

6.3.2.10 Purchase bids (BRP)

The purchase bids that the BRP present on behalf of the retailers are paid at the market price, which is decided by the matchmaking algorithm executed by the market operator:

$$Market\ price_y = \sum_{h=1}^{8760} Hourly\ market\ price_h * Market\ electricity\ consumption_h$$

6.3.2.11 Sale bids (BRP)

Analogously, the sale bids that the BRP present on behalf of DER Producers are also paid at the market price:

$$Market\ price_y = \sum_{h=1}^{8760} Hourly\ market\ price_h * Market\ electricity\ production_h$$

6.3.2.12 Payment for imbalance (DER Producer)

Exactly in the same fashion as the retailer, the DER Producer has to pay to the BRP for the deviations from the expected production used for the energy purchase to the real injected energy.

$$Payment\ for\ imbalance_y = \sum_{h=1}^{8760} Hourly\ imbalance\ price_h * Imbalance_h$$

6.3.2.13 Representation (DER Producer)

The DER Producer pays to the BRP for representing its interests in the business of energy selling. The BRP internalizes the risk of not being able to sell the production of the RES to either a retailer or in the market, so this representation fee has to include that risk coverage.

$$Annual\ representation\ fee_y = \sum_{d=1}^{365} Daily\ representation\ fee_d$$

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6.3.2.14 Bilateral and market electricity production

Analogously to the retailer, but referred to production instead to consumption, the DER Producer can sell its production at the market or directly to a retailer. We consider here the criteria commented in the Bilateral electricity production and Market electricity production exchange, for the decision about the energy sale place and the price.

$$Market\ price_y = \sum_{h=1}^{8760} Hourly\ market\ price_y * Market\ electricity\ production_h$$

And

$$Bilateral\ price_y = \sum_{h=1}^{8760} Hourly\ market\ price_y * Bilateral\ electricity\ production_h$$

6.3.2.15 Grid access (DER Producer)

For the DER Producer, it is compulsory to pay for the T&D fees. The calculation of the exchange follows identical rules to those described in the grid access fee paid by the retailer.

$$T\&D\ Fee_y = \sum_{h=1}^{8760} T\&D\ Energy\ term\ price_h * Energy\ demand_h$$

6.3.2.16 Grid curtailment

Avoiding curtailment of renewable energy production due to distribution grid constraints violations (grid curtailment) would require investing in capacity in the DSO network, which would be very costly. Besides, if we take into account that this action would be executed for few hours annually, it is understandable that DSOs would prefer to compensate DER Producers for their losses in energy production. The possible compensation would be based on market prices and/or subsidies.

Two possible schemes could be used for grid curtailment, voluntary or involuntary.

DER Producers can accept voluntary curtailment in their contracts related to the grid connection, due to grid constraints. By this acceptance, DER Producers could have a discount on the initial connection charges at the moment of connection to the grid. This case applies mostly when the DER Producer directly or indirectly finances the connection lines to the network, and accepts to be curtailed due to a constraint in its own connection cable. Then the DER Producer has to decide if it prefers to install a higher capacity cable, and avoid the curtailment, or the contrary. Obviously, there is no compensation for this kind of curtailment and it is considered out of scope of the FHP project studies.

Involuntary curtailment can take place temporarily due to delays in infrastructure investment relative to generation capacity, due to the slower pace of network retrofit compared to renewable penetration rate. In this case, the network owner (DSO) would be obligated to compensate the generator at least partly for the loss incurred. The costs of curtailment would be settled in terms of lost generation (grid curtailment energy), based on the kind of remuneration that the DER Producer would have obtained.

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In the FHP business model, we assume that the incomes that the DER Producer gets are based on market prices complemented with GHG subsidies, so the compensation will be proportional to these costs. The multiplying factor (grid curtailment factor) would be regulated depending on the country legislation.

$$Compensation\ for\ grid\ curtailment_y = \sum_{h=1}^{8760} Grid\ curtailment\ energy_y * Grid\ curtailment\ factor * (DER\ subsidies + Market\ price)_h$$

6.3.2.17 Commercial curtailment

Commercial curtailment can occur due to market design, when DER Producers face the risk that their sale bids are not accepted by the market operator. In those circumstances, there is not sufficient demand in the energy market, when taking into account system operational restrictions for security of supply, i.e. a combination of low demand, excess of renewable production and technical minima of plants ("must-run" obligations of nuclear od combined cycle plants) which might lead to system security issues.

Curtailment compensation schemes are needed in order to limit market risk and thus ensure technology financing costs are not disproportionate. Compensation should be related to the foregone revenue (lost opportunity), so as in the case of grid curtailment due to grid constraints, related to the market prices and the GHG subsidies.

$$Compensation\ for\ commercial\ curtailment_y = \sum_{h=1}^{8760} Commercial\ curtailment\ energy_y * Commercial\ curtailment\ factor * (DER\ subsidies + Market\ price)_h$$

6.3.2.18 GHG emission reduction

The government remunerates the production to the DER Producers by their contribution to the GHG emission reduction. The incentives are regulated by law and are based on the type of technology, installed power, coming into operation year, etc. This segmentation of subsidies is reflected by the premium for DER factor.

$$DER\ subsidies_y = \sum_{h=1}^{8760} (Bilateral\ electricity\ production + Market\ electricity\ production)_y * Premium\ for\ DER_h$$

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6.3.2.19 DA/ID phase flexibility (DSO)

The exchange between the Aggregator and the DSO about negotiation phase flexibility is billed depending on the prices of the flexibility market managed by the DSO. These prices are offered by the aggregator when the flexibility offer is sent to the DSO, and the DSO decides if it accepts them or not. Flexibility is paid by the DSO for each kWh contracted by the DSO to the aggregator. Contracted flexibility will be verified with real measurements, so that just verified flexibility will be reimbursed.

$$Retribution\ for\ negotiation\ phase\ flexibility_y = \sum_{h=1}^{8760} Flexibility\ price_h * Negotiation\ phase\ flexibility_h$$

6.3.2.20 DA/ID phase flexibility (BRP)

The exchange between the Aggregator and the DSO about negotiation phase flexibility is also billed depending on the prices freely agreed between BRP and the aggregator in the flexibility negotiation phase.

$$Retribution\ for\ negotiation\ phase\ flexibility_y = \sum_{h=1}^{8760} Flexibility\ price_h * Negotiation\ phase\ flexibility_h$$

6.3.2.21 real-time phase flexibility (BRP)

As it occurs with the DSO, here it is the BRP the one that determines on its own the price that it pays for flexibility, depending on the capacities (requested price vs flexibility) previously communicated by the aggregator:

$$Payment\ for\ balancing\ service_y = \sum_{h=1}^{8760} Balancing\ service\ price_h * Operation\ phase\ flexibility_h$$

6.3.3 Cash Flow formulation

In this section, the final outcome is to provide the cash flow formulation for each role, taking into account the defined formulation of exchanges.

The cash flow for the Heat User depends strictly on the price paid to the Heat Provider for the provision of the Heating Service:

$$CF_{HU} = -Heating\ service$$

The cash flow for the Heat Provider is:

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$$CF_{HP} = Service\ fee - Retail\ price\ electricity \mp Incentive\ for\ flexibility - Annual\ subscription\ fee$$

Being:

- *Service fee* the price received by the Heat User for the provision of the Heating service
- *Retail price electricity* the price paid to the retailer for the consumed energy, sum of the *baseline electricity consumption* and *flexible electricity consumption*
- *Incentive for flexibility* the price received by the aggregator depending on the increase/decrease of consumption compared to the baseline, *consumption flexibility*
- *Annual subscription fee* the price paid to the aggregator for the provision of the *aggregation service*

The cash flow for the Retailer considers as the only income the payment from Heat Providers, while all the other terms represent expenditures:

$$CF_R = Retail\ price - Payment\ for\ imabalance - Annual\ fee - Bilateral\ price - Market\ price - T\&D\ fees$$

The cash flow for the BRP is the most complex one, as it takes into account the exchanges with the aggregators, retailers, DER Producers and other electric regulated roles:

$$\begin{aligned} CF_{BRP} = {} & Payment\ for\ imabalance\ (Retailer) \\ & + Payment\ for\ imabalance\ (DER\ Producer) - ImbalancePrice \\ & - Retribution\ for\ negotiation\ phase\ flexibility \\ & - Payment\ for\ balancing\ service \\ & - Compensation\ for\ commercial\ curtailment \\ & + Annual\ fee (Retailer) + Annual\ fee\ (DER\ producer) \\ & + Bilateral\ price\ (Retailer) + Market\ price (Retailer) \\ & - Market\ price\ (purchase\ bids) - Bilateral\ price\ (DER\ producer) \\ & - Market\ price (DER\ prducer) + Market\ price\ (sale\ bids) \end{aligned}$$

The incomes in the cash flow of the DER Producer are derived from its energy sales, complemented with subsidies, or the compensation because of curtailment, while its expenditures are due to imbalances and BRP's representation fees.

$$\begin{aligned} CF_{DER} = {} & Bilateral\ price + Market\ price - T\&D\ fees \\ & + Compensation\ for\ commercial\ curtailment \\ & + Compensation\ for\ grid\ curtailment - Payment\ for\ imbalance \end{aligned}$$

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The aggregator's cash flow depends on the incomes from the DSO and BRP for the flexibility provided, the income from Heat Providers for the aggregation service and the spending on incentives to Heat Providers:

$$CF_A = Retribution\ for\ negotiation\ phase\ flexibility\ (DSO) + Retribution\ for\ negotiation\ phase\ flexibility\ (BRP) + Payment\ for\ balancing\ service - Incentive\ for\ Flexibility$$

Finally, the cash flow for the DSO just takes into account the costs of grid curtailment and flexibility:

$$CF_{DSO} = -Retribution\ for\ negotiation\ phase\ flexibility - Compensation\ for\ grid\ curtailment$$

6.3.4 Cost benefit analysis

A cost benefit analysis (CBA) assesses the cash flows of the different actors in certain conditions, with the objective of establishing if the business relationship among them is feasible or not. The recreation of the conditions in which these actors would exchange value is crucial as it influences directly the estimation of the profit that each actor would get. This assessment should be included in feasibility studies about the exploitation and deployment of the FHP flexibility management solution in the scope of the developed business use cases in a certain country conditions.

In order to assess the viability of the deployment of the FHP technology in the future at a large scale, we have concentrated our efforts in the study of a country wide scenario. As the evaluation of the conditions that apply are both derived from the availability of statistical data and measurements from the pilot sites, and majorly about the flexibility that can be provided by heat pump installations thanks to the FHP modelling and model based predictive control, we have focused the study on the conditions encountered in Sweden.

The outcome of this analysis is the effect on the incomes that each main actor with active participation (the DER producer, the Heat User, the Heat Provider, the BRP, the DSO and the aggregator) has due to its inclusion in the FHP flexibility management solution. Therefore, the analysis is based on the cost benefit assessment in these two scenarios:

- ✓ the reference scenario, which describes the initial situation in which there is no flexibility management, what we call **BAS** (Business As uSual) **scenario**.

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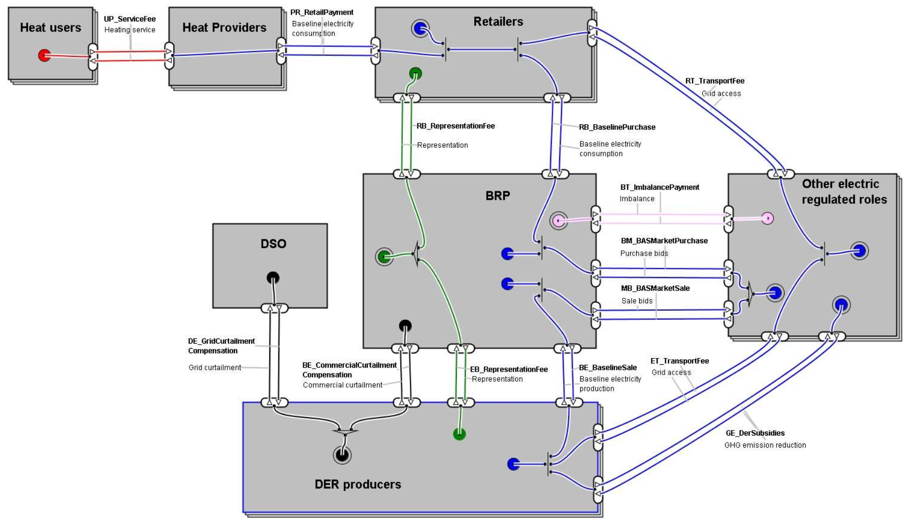

Figure 41: BAS scenario

- ✓ in a modified scenario where flexibility is provided with the FHP technology deployed, what we called the **FHP scenario**. In this scenario a new actor, the DCM, aggregates the flexibility from Heat Providers and sells it to the DSO and BRP in the scope of the FHP business cases.

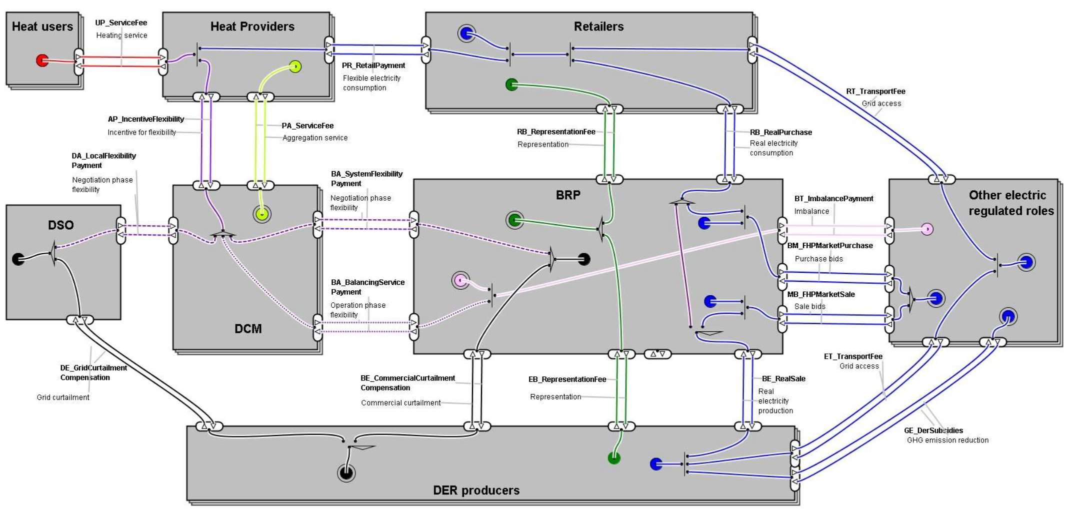

Figure 42: FHP scenario

To define each monetary transaction, we create a naming convention composed by three items:

- ✓ *SCENARIO*: BAS or FHP
- ✓ *ACTORS*: Two letters identifying which actor is paying to which actor. For instance, UP, means the Heat User pays to the Heat Provider. See ***Table 8***
- ✓ *EXCHANGE*: The name of the exchange as defined in the 6.3.2 section

Actor	Acronym
Aggregator	A
BRP	B

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DER producer	E
DSO	D
Government	G
Heat Provider	P
Heat User	U
Market operator	M
Retailer	R
TSO	T

Table 8: Acronym used for each actor in CBA

The following example illustrates this approach: FHP_AP_IncentiveFlexibility. This identifies a transaction that takes place in the FHP scenario between the Aggregator and the Heat Provider for the heating service, where the Aggregator pays an incentive to the Heat Provider to stimulate its flexibility.

6.3.4.1 Simulation. Sweden data

In this section we describe the data that we have used for the analysis of how a massive deployment of the FHP in Sweden nowadays (2019) would result in terms of economic benefit for each active participating actor. The analysis is done for a whole year based on the coordinated and prioritized application of the three use cases that we have developed in the project over the trial period. With this approach, flexibility from the Heat Providers is requested from the DSO or the BRP for the different use cases based on real 2018 data both from country available electric system operation databases, statistical studies and data coming from our experts gathered through the execution of the FHP project pilots in Karlshamn. The granularity of the data is 15 minutes, so each day of the year is divided in 96 PTU periods.

In the online system flexibility is negotiated in UC1 and UC2 for the day ahead and intraday periods, and for UC3 in the beginning of each PTU. But in this offline simulation, in order to be able to decouple the effects of each use case, we have established a priority rule which sets the use case to be applied in each 15-minute PTU.

- ✓ The use case with the highest priority is UC1, Local RESCurtailmentMitigation, where the DSO requests flexibility to avoid local grid congestions due to a local renewable production excess.
- ✓ If flexibility is not requested by the DSO on that PTU, the second use case with the highest priority has the chance to be applied, SystemRESCurtailmentMitigation. In that use case, the BRP pays for flexibility to avoid the curtailment of renewable energy due to distorted market conditions.
- ✓ And in those PTUs in which flexibility has not been ordered from UC1 and UC2, is when UC3, BalancingServices, can be applied. In this use case the BRP uses flexibility to act on the imbalance position of its portfolio.

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6.3.4.1.1 Heat User

In Sweden, at the end of 2016, there were nearly 4,8 million buildings[87]. In the residential sector, there were 2.053.665 dwellings one- dwelling or two-dwelling buildings and 2.663.115 in multi-dwelling buildings. One- dwelling or two-dwelling buildings refer to detached one- and two-dwelling buildings as well as semi-detached, row and linked buildings. Multi-dwelling buildings refer to buildings with three or more apartments, including balcony access housing and special housing which refers to dwellings for the elderly/disabled, student housing and other special housing. In commercial premises, in 2016 there were 78.937 commercial buildings, which are buildings not intended for residential purposes, for example, buildings used for business or public activities. Commercial buildings are usually classified into industrial, logistics, retail and office multiplex buildings [66].

In our analysis, we define four types of Heat Users:

- ✓ SFB: Single dwelling building
- ✓ MFB: Multi dwelling building
- ✓ Office
- ✓ Commercial

We estimate that for 2019 the number of heat users of each type would be:

Name	**Units**	**Type1**	**Type2**	**Type3**	**Type4**
		SFB	**MFB**	**Office**	**Commercial**
UP_Type		Residential	Residential	Commercial	Commercial
Number		2.500.000	3.000.000	50.000	50.000

Table 9: Number of dwellings in the Swedish stock

The size of the average dwelling in multi-dwelling buildings is 68 square metres, while the size of the average one- or two-dwelling building is 122 square metres. The average surface of both office and commercial building is taken from the European Heat Pump Association (EHPA) report [67].

Name	**Units**	**Type1**	**Type2**	**Type3**	**Type4**
		SFB	**MFB**	**Office**	**Commercial**
UP_Surface	m2	122	68	2.000	620

Table 10: UP_Surface

In Sweden, based on the 2018 report of the EHPA, the annual thermal energy demand per building type is the following (units in kWht/m2):

[87] http://www.scb.se/en/finding-statistics/statistics-by-subject-area/housing-construction-and-building/housing-construction-and-conversion/dwelling-stock/pong/statistical-news/dwelling-stock-2016-12-31/

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	AT	BE	FR	DE	IT	ES	SE	UK
Space Heating Demand								
Single-Family House	61.2	75.9	97.6	82.2	40.2	57.3	60.7	58.7
Multi-Family House	80.7	90.5	90.4	104.3	35.2	64.2	49.9	73.8
Office	45.8	53.8	56.5	39.8	18.6	39.9	37.1	48.2
Space Cooling Demand								
Single-Family House	0	0	0	0	11.2	10.5	0	0
Multi-Family House	0	0	0	0	25.3	26.1	0	0
Office	14.3	4.5	6.6	2.5	32.6	28.0	6.8	4.0

Table 11: Heating demand. Source EHPA

If we use an average COP value of 2 (taken from the average value of the real COP of the HP in the RISE villa[88] for all seasons), and given the estimated average surfaces (see ***Table 10***), in Sweden the annual electricity demand for each Heat User in which heating and DHW is covered by heat pumps would be:

- ✓ SFB: 60,7 * 122/ 2 = 3.702,7 kWh
- ✓ MFB: 49,9 * 68 / 2= 1.696,6 kWh
- ✓ Office: 37,1 * 2000 / 2= 37.100 kWh
- ✓ Commercial: 37,1 * 620 / 2= 11.501 kWh

Name	Units	Type1	Type2	Type3	Type4
		SFB	**MFB**	**Office**	**Commercial**
AnnualThermalConsumption	kwht/m^2	60,7	49,9	37,1	37,1
AverageCopValue		2	2	2	2
TotalAnnualElectricConsumption	kWhe	3.702,7	1.696,6	37.100	11.501

Table 12: TotalAnnualElectricConsumption

These estimations are supported by these three complementary considerations:

- ✓ In the RISE villa the yearly average power consumption of the heat pump is 410 W , so for a year then the total energy consumption would be 3.591,6 kWh. This is in line with the value calculated for the single dwelling-villa heat user type.
- ✓ For commercial buildings, we use the winter daily profiles from [68], and the ratio between the total energy spent for each season from the data on HeatUserType1 (SFDs).
- ✓ The average consumption is maximum for houses with electric heating where families or couples without children between 26 and 64 years old are living: 18.558 kWh/year and 17.173 kWh/year respectively.

For residential Heat Users, we base our analysis in the baseline electricity consumption profile measured in the RISE villa, for the different seasons of the year.

[88] The RISE villa is a research installation that represents a SFB in Sweden, which as been used in the FHP Project to develop the termal response building models

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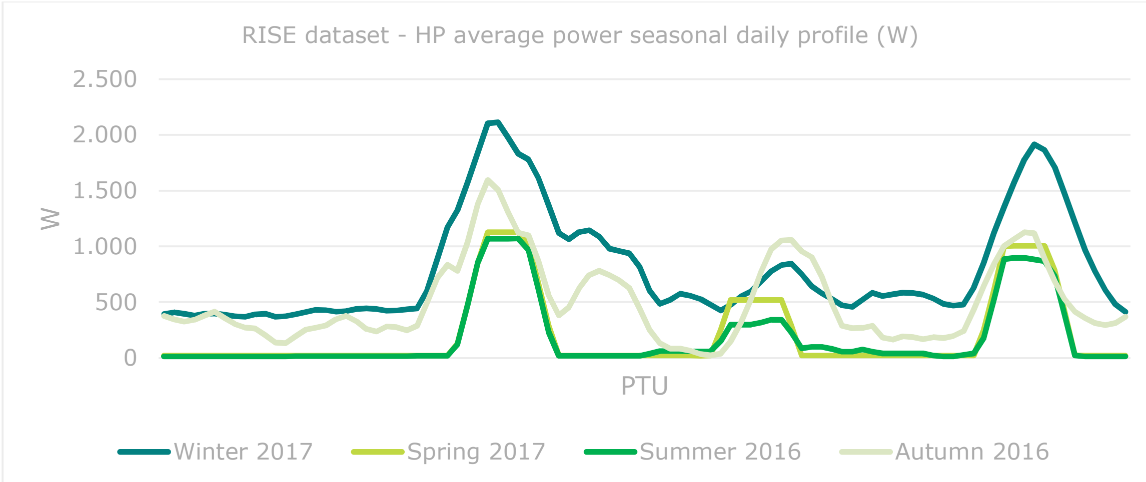

Figure 43: Residential daily seasonal heat pump 15 minutes average power consumption

For commercial heat users, we base our analysis on the consumption data gathered in the commercial trial sites:

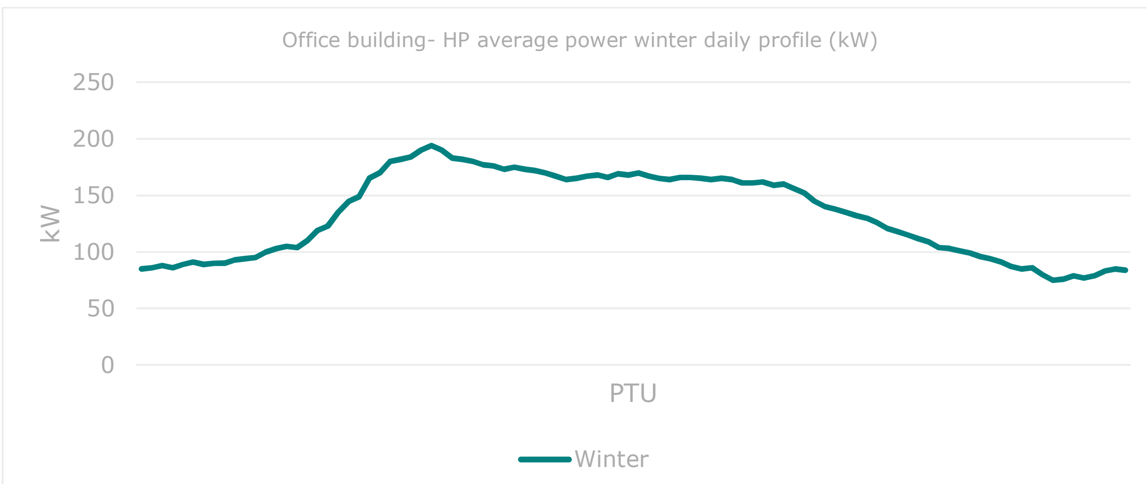

Figure 44: Commercial daily heat pump 15 minutes average power consumption

Given the TotalAnnualElectricConsumption of each HeatUser, calculated as:

$$TotalAnnualElectricConsumption = AverageCOPValue * AnnualThermalConsumption * UP\_Surface$$

We set the electric consumption profile of each Heat User to the following values:

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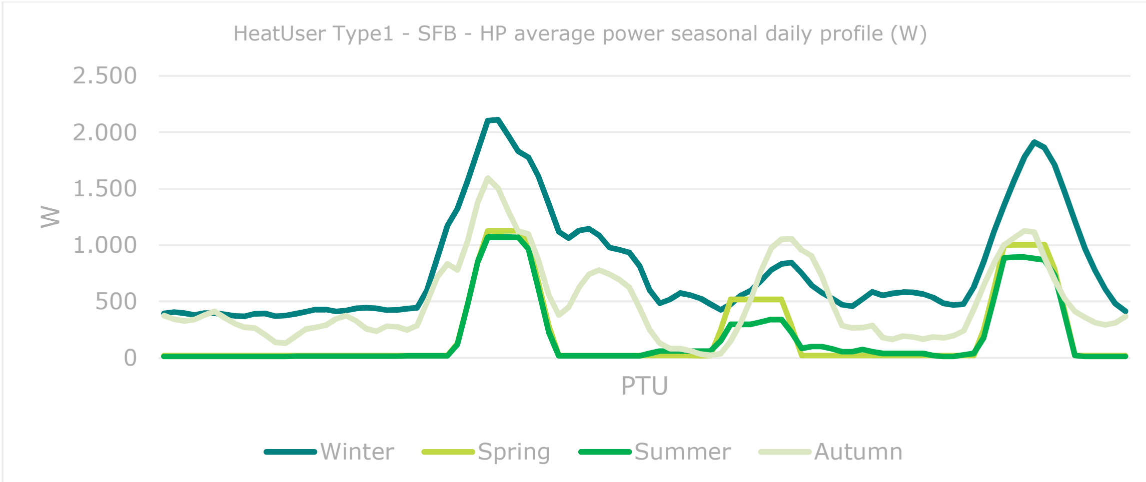

Figure 45: Heat User of type 1 consumption profile

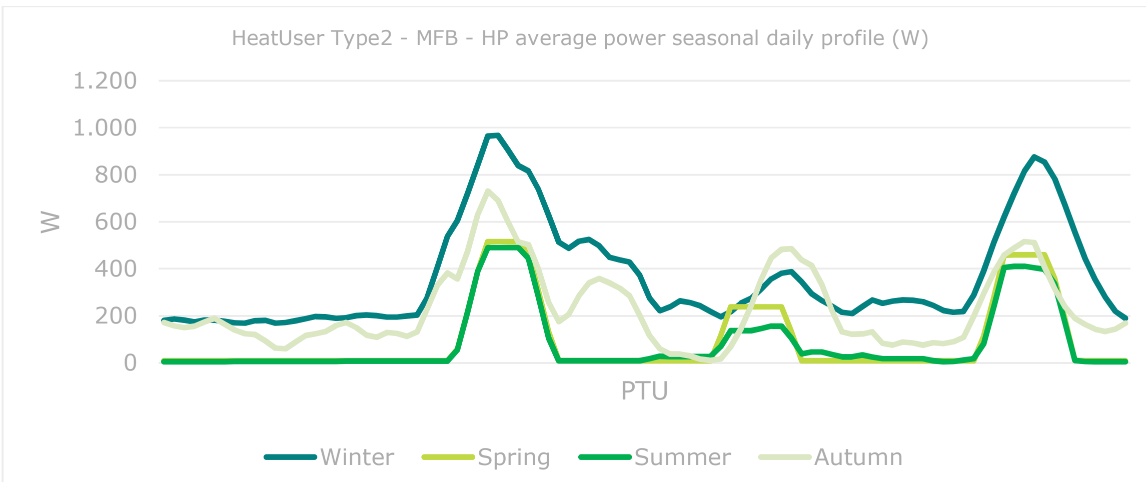

Figure 46: Heat User of type 2 consumption profile

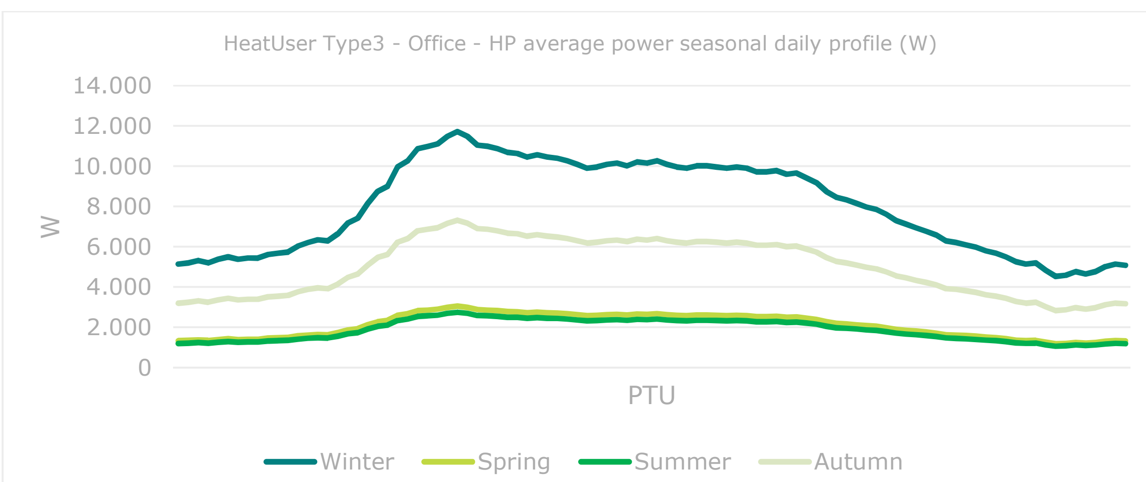

Figure 47: Heat User of type 3 consumption profile

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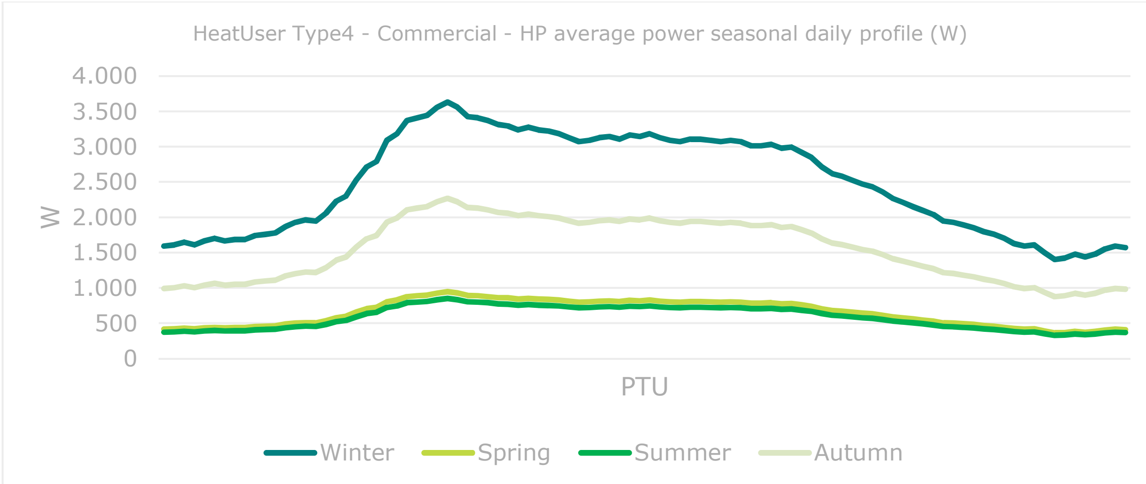

Figure 48: Heat User of type 4 consumption profile

Based on the prospective of the European Heat Pump association, [67], we consider an ambitious heat pump scenario with increasing shares of heat pumps in new buildings and retrofits (target: 50% share for new buildings in 2030 and 30% in retrofits in 2030). The current (2018) 20,6% share of heating primary source in buildings is heat pumps is expected to increase to 50% in 2030 [69]. The low level of electric heating use in MFDs is because 92% of the MFDs are connected to the district heating grid [70]. We assume in our analysis that 100% of the heat pumps would be enrol in the FHP system (FHP_Share). We start the analysis assuming that the HP_Share, which is the share of heat users which have heat pumps for heating is the 50%, but this parameter will be the target of a sensitivity analysis, so that assessing different future scenarios in which the penetration ratio of heat pumps is different we can evaluate the effect of this ratio in the profitability of the FHP deployed technology and in the expected curtailment mitigation.

Name	Units	Type1	Type2	Type3	Type4
		SFB	MFB	Office	Commercial
HP Share		50	50	50	50
FHP Share		100	100	100	100

Table 13: HP Share and FHP_Share

The transaction between the Heat User and the Heat Provider, due to the heating service exchange, is based on the exchange of money for the provision of a heating service on a yearly basis.

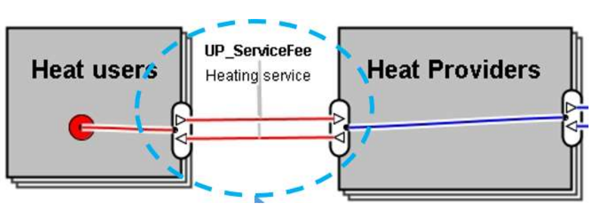

Figure 49: BAS_UP_ServiceFee

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$$BAS\_UP\_ServiceFee = UP\_YearlyServiceFee$$

Where:

$$UP\_YearlyServiceFee = UP\_YearlySurfaceServiceFee * UP\_Surface$$

The heating service provided by the Heat Provider to the Heat User has to be related to the cost of the electricity paid by the Heat Provider to operate the heating of a Heat User of certain UP_Surface in confort conditions.

The thermal service paid by the Heat User to the Heat Provider, UP_YearlyServiceFee, is referenced to the price of the electricity paid by the Heat Provider to cover the annual thermal consumption with a heat pump, with an economic profit factor of 2[89].

$$UP\_YearlySurfaceServiceFee = (AnnualThermalConsumption * AverageElectricityPrice)/(AverageCopValue * 100)$$

According to the EU[90], the average retail price of electricity in Sweden (second half of 2018) was 20c€/kWh. During that period the average price of the Elspot market was 31,5887 €/MWh, so the PR_RetailerBusinessFactor was 6,34. For residential users, in 2018 the average price of electricity was 19,93 c€/kWh[91] while for industrial users, during the same period the average price of electricity was 6,36 c€/kWh[92]. Market prices are retrieved from the Swedish market operator[93] (SE1 area, day ahead market prices in 2018).

We assume that the Heat Provider can sell its heating service to the Heat User based on the price that a residential consumer would pay to the retailer for serving the P2H system, plus an overhead for the operation and amortization of the P2H system, which would double the electricity cost. In any case, the cost reference for AverageElectricityPrice would be around 40 c€/kWe.

Name	Units	Type1	Type2	Type3	Type4
		SFB	MFB	Office	Commercial
UP_Surface	m2	122	68	2000	620
AnnualThermalConsumption	kwht/m2	60,7	49,9	37,1	37,1
AverageElectricityPrice	c€/kWhe	40	40	40	40
AverageCopValue		2	2	2	2
TotalAnnualElectricConsumption	kWhe	3.702,7	1.696,6	37.100	11.501
UP_YearlySurfaceServiceFee	€/m2	12,14	9,98	7,42	7,42

Figure 50: UP_YearlySurfaceServiceFee

There should be also in the economic transaction with the Heat Provider a term that has to comply with the deviations on the consumption due to override capacity available at the Heat User side. This

[89] https://www.statista.com/statistics/418124/electricity-prices-for-households-in-sweden/
[90] http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics
[91] https://www.statista.com/statistics/418124/electricity-prices-for-households-in-sweden/
[92] https://www.statista.com/statistics/418124/electricity-prices-for-households-in-sweden/
[93] https://www.nordpoolgroup.com/Market-data1/Dayahead/Area-Prices/ALL1/Hourly/?view=table

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term should be a function of the energy surplus that the Heat Provider, Energy Overridden, must face in case of override. There should be an agreement of the price to which the Heat Provider would bill this energy, the verride price.

$$FHP\_UP\_ServiceFee = UP\_YearlyServiceFee + \sum_{q=1}^{4*8760} UP\_EnergyOveridenPayment_q - \sum_{q=1}^{4*8760} UP\_ComfortPenaltyPayment_q$$

There is a contract between the Heat Provider and the HeatUser so that the Heat Provider is obligated to operate the P2H system so that the average facility temperature, *UP_AverageRealTemperature*, is between the *UP_HighestAverageTemperature* and the *UP_LowestAverageTemperature*.

$$UP\_LowestAverageTemperature_q \leq UP\_AverageRealTemperature_q \leq UP\_HighestAverageTemperature_q$$

Then:

If $UP\_AverageRealTemperature_q > UP\_HighestAverageTemperature_q$

$$UP\_TemperatureRangeDeviation_q = UP\_AverageRealTemperature_q - UP\_HighestAverageTemperature_q$$

If $UP\_AverageRealTemperature_q < UP\_LowestAverageTemperature_q$

$$UP\_TemperatureRangeDeviation_q = UP\_AverageRealTemperature_q - UP\_LowestAverageTemperature_q$$

The average room temperature in office buildings uses to be between 21 and 24 ºC, although legislation defines a comfort range of 18-23 ºC [70]. In residential housing the upper limit would be a bit lower.

Name	Units	Type1	Type2	Type3	Type4
		SFB	MFB	Office	Commercial
UP_HighestAverageTemperature	ºC	22	22	23	23
UP_LowestAverageTemperature	ºC	18	18	18	18

Table 14: Confort range

If the measured temperature has an excursion outside the permitted range, the HeatUser will receive a compensation from the Heat Provider that will be proportional to the *UP_TemperatureRangeDeviation*:

$$UP\_ComfortPenaltyPayment_q = UP\_TemperatureRangeDeviation_q * UP\_ComfortPenaltyPrice$$

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On the contrary, the HeatUser has always the freedom to override the automatic operation of the P2H systems by the Heat Provider, imposing a manual local control in some periods in which *UP_OverideSignal = true*. Under these circumstances, the Heat User will have to pay *UP_OveridePrice* for each PTU. We assume that this value could be 10 times the price the Heat User is paying daily to the Heat Provider for the service → $\frac{10 * UP_{YearlyServiceFee}}{365}$

Being:

- $UP\_OveridePayment_q = UP\_OveridePrice$ when $UP\_OverideSignal_q = false$
- $UP\_OveridePayment_q = 0$ when $UP\_OverideSignal_q = false$

The price applied to the overridden in each time slot, *UP_OveridePrice*, is agreed by contract between the HeatUser and the Heat Provider

$$UP\_ComfortPenaltyPayment_q = UP\_EnergyOveriden_q * UP\_OveridePrice$$

Based on the pilot tests in Sweden, we have checked that the FHP direct control strategy of the heat pumps would assure that the indoor temperature accepted range would always be satisfied, so the Heat User will not receive a compensation from the Heat Provider for comfort penalties, and thanks to this, the Heat User would never override the system. Due to these reasons the cash flow of the Heat User would be identical in the BAS and FHP scenarios.

Given this information, we assume that the heat user conditions applied in the analysis should be:

Name	Units	Type1	Type2	Type3	Type4
		SFB	MFB	Office	Commercial
UP_Type		Residential	Residential	Commercial	Commercial
HP Share		50	50	50	50
FHP Share		100	100	100	100
MaxPower	kW	6,34	2,91	63,53	19,69
MaxPowerFactor	%	1.500	1.500	1.500	1.500
UP_Surface	m^2	122	68	2000	620
UP_HighestAverageTemperature	ºC	22	22	23	23
UP_LowestAverageTemperature	ºC	18	18	18	18
UP_ComfortPenaltyPrice	€/ºC	2	2	2	2
AnnualThermalConsumption	$kWht/m^2$	60,7	49,9	37,1	37,1
AverageElectricityPrice	c€/kWhe	40	40	40	40
AverageCopValue		2	2	2	2
TotalAnnualElectricConsumption	kWhe	3702,7	1696,6	37100	11501
UP_YearlySurfaceServiceFee	$€/m^2$	12,14	9,98	7,42	7,42
UP_YearlyServiceFee	€	1.481	679	14.840	4.600
UP_OveridePrice	€	41	19	407	126

Table 15: Heat user conditions

As stated before, as the Heat User economy is not affected by means of the FHP system, its differential cash flow, CF_HeatUser, is 0.

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Name	Units	Type1	Type2	Type3	Type4
		SFB	MFB	Office	Commercial
BAS_UP_ServiceFee	€	1.481	679	14.840	4.600
FHP_UP_ServiceFee	€	1.481	679	14.840	4.600
BAS_CF_HeatUser	€	-1.481	-679	-14.840	-4.600
FHP_CF_HeatUser	€	-1.481	-679	-14.840	-4.600
CF_HeatUser	€	0	0	0	0

Table 16: Heat user cash flow

6.3.4.1.2 Heat Provider

About the relationship of how many heat users, heat providers and aggregators would be defined we set the following rules:

- ✓ For Heat Users of type 1, we would have a Heat Provider for each Heat User, as in single-dwelling buildings the building owner usually plays both roles of the Heat User and the Heat Provider.
- ✓ For Heat Users of type 2, we would have a Heat Provider for each 40 Heat Users, as there would ba a unique heat pump installation to cover the thermal demand of all the multi-dwelling building.
- ✓ For Heat Users of type 3, we would have a Heat Provider for each Heat User, as the HVAC of one office building uses to be independent of other office building.
- ✓ For Heat Users of type 4, we would have a Heat Provider for each 10 Heat User, as commercial sites uses to be aggregated in malls with centralised heating services.
- ✓ For simplicity, we would have an Aggregator for all Heat Providers. This lets us calculate the benefit of deploying the FHP solution for the aggregation business in general. If multiple aggregators would exist, a share factor would be used.

Name	Units	SFB	MFB	Office	Commercial
Number		1.250.000	37.500	25.000	2.500
Number HeatUsers TypeX		1,00	40,00	1,00	10,00

Table 17: Number of each type of Heat Providers

With this aggregation figures, sizing the PR_ContractedPower of each Heat Provider as the sum of the MaxPower of its Heat Users, which is the maximum power that it can instantaneously consume, PA_MaxPower.

Name	Units	SFB	MFB	Office	Commercial
PR_ContractedPower	kW	6,34	116,21	63,53	196,93
PA_MaxPower	kW	6,34	116,21	63,53	196,93

Table 18: Max power

The cash flow of the Heat Provider in the BAS scenario, BAS_CF_HeatProvider, is only affected by:

- ✓ the money received from the Heat Users, BAS_UP_ServiceFee multiplied by the number of users of each type,
- ✓ and the bill paid to the retailer, BAS_PR_RetailPayment.

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Being

$$BAS\_PR\_RetailPayment = PR\_RetailerBusinessFactor * PR\_BaselineElectricityPayment$$

and being

$$PR\_BaselineElectricityPayment = (BM\_DayAheadMarketPrice * PR\_BaselineElectricityConsumption)/100$$

as the retailer buys the electricity in the spot market.

The baseline electricity consumed by the Heat Provider would be paid at the retail price agreed by both parties. This price is fix, so that both parties know it before consumption occurs. But it could be revised periodically, to adapt it to the last prices of the spot markets. The revision period could be annual. Different prices could be adopted for the different times of day or for different day types, based on the assumption of the dynamic tariff scheme (Time of Use).

In fact, in the field there will be no way to measure the baseline, as the baseline is the estimation of how much electricity would have consumed the Heat Provider if no flexibility has been provided. We would use then the baseline calculated by the Heat Provider for the settlement of the baseline electricity consumption.

Name	Units	SFB	MFB	Office	Commercial
PR_BaselineElectricityConsumption	kWh	3.703	67.864	37.100	115.010
BAS_PR_RetailPayment	€	1.328	24.340	13.074	40.530

Table 19: BAS_PR_RetailPayment

The retailer charges to the Heat Provider a dynamic tariff based on the DAM prices, multiplied by a factor to include its management costs and its profit expectations. This is applied to the consumption of the (controllable) P2H systems. In our case, we adjust the retailer business factor so that the price paid by the Heat Provider for electricity is smaller than the money received from Heat Users for the heating service, so that the Heat Provider has a certain gain:

Name	Units	SFB	MFB	Office	Commercial
BAS_UP_ServiceFee	€	1.481	27.146	14.840	46.004
BAS_PR_RetailPayment	€	1.328	24.340	13.074	40.530

Table 20: Heat Provider income and spending

	Units	Value
PR_RetailerBusinessFactor	-	8,00

Table 21: Retailer business factor

To mimic the payback effect associated to flexibility provision in HVAC systems with thermal inertia, we have designed a virtual energy storage for each Heat Provider. For buildings without on purpose water tanks for energy storage, we assume that the thermal inertia stored at the building constructive elements, P_ThermalInertiaSize, is around half the PR_ContractedPower. That represents the capacity that the BMES has either to forward or to postpone the heating of the building, without

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affecting the Heat Users because of excursions outside the pre-agreed comfort range for the indoor temperature.

Related to this, we set a P_ThermalInertiaTarget of the -75% of the P_ThermalInertiaSize, which means that the building is mostly in a preheating default state, having the 75% of its P_ThermalInertiaSize ready for consumption increase upon aggregator request, and 25% for consumption decrease. We have set these limits because flexibility in UC1 and UC2 is only requested for consumption increase, and as we will explain later, in UC3 the flexibility requested is also majorly for consumption increase. With these value of P_ ThermalInertiaSize, the BEMS can recover the P_ThermalInertiaTarget in one time unit.

Name	Units	SFB	MFB	Office	Commercial
P_ThermalInertiaTarget	kWh	-2,38	-43,58	-23,82	-73,85
P_ThermalInertiaSize	kWh	3,17	58,10	31,76	98,47

Table 22: Thermal inertia

In the FHP scenario, the heat user service fee is identical, BAS_UP_ServiceFee = FHP_UP_ServiceFee, but the payment to the retailer varies, as the consumption varies. In this case the baseline consumption is replaced by the real consumption, as the incentives that will be used are absolute. Real consumption is calculated with the flexible consumption (after day ahead negotiation with DSO and BRP) and consumption decrease/increase due to balancing services

$$FHP\_PR\_RetailPayment = PR\_RetailerBusinessFactor * PR\_RealElectricityPayment$$

Being:

$$PR\_RealElectricityPayment = (PR\_RealElectricityConsumption * BM\_DayAheadMarketPrice) * 100$$

Being PR_ModifiedElectricityConsumptionUCX the consumption variation due to UC1 and UC2, and PR_BalancingConsumptionIncreaseEnergy and PR_BalancingConsumptionDecreaseEnergy the consumption variation due to UC3:

$$PR\_RealElectricityConsumption = PR\_FlexibleElectricityConsumption + PR\_BalancingConsumptionIncreaseEnergy - PR\_BalancingConsumptionDecreaseEnergy + P\_ThermalInertiaRecovery$$

And

$$PR\_FlexibleElectricityConsumption = PR\_BaselineElectricityConsumption + PR\_ModifiedElectricityConsumptionUC1 + PR\_ModifiedElectricityConsumptionUC2$$

Name	Units	SFB	MFB	Office	Commercial
PR_RealElectricityConsumption	kWh	3.727	68.301	37.427	116.005
FHP_PR_RetailPayment	€	1.329	24.364	13.182	40.855

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Table 23: FHP_PR_RetailPayment

P_ThermalInertiaRecovery represents the action of the local BEMS (Building Energy Management System) that tries to recover the P_ThermalInertiaTarget when flexibility is not requested for the current time unit. This is the mechanism that guarantees that the Heat Provider cannot provide more flexibility that what it is supposed to do and implements the recovery mechanism that mimics the payback effect of providing flexibility.

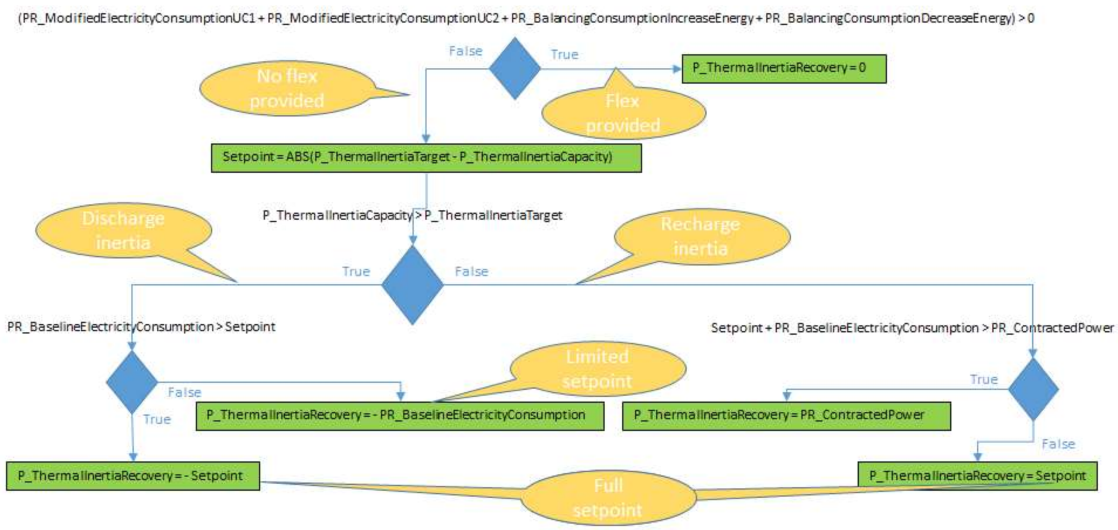

Figure 51: Thermal Inertia recovery mechanism

The flexibility that a certain Heat Provider can provide is represented by the P_ThermalInertiaSize. This represents the maximum energy that the building, in which the HVAC operated by the Heat Provider is located, can either forward or postpone with respect to the PR_BaselineElectricityConsumption. Then, at each time unit, the evolution of that thermal inertia capacity is represented by P_ThermalInertiaCapacity, where positive values represent energy stored for ulterior use (preheating of the building), and negative values the contrary.

$$
\begin{aligned}
P\_ThermalInertiaCapacity(t) \\
&= P\_ThermalInertiaCapacity(t-1) + PR\_RealElectricityConsumption \\
&- PR\_BaselineElectricityConsumption
\end{aligned}
$$

As the logic implemented with the thermal inertia recovery strategy, aims to mimic the payback effect that flexibility provision would have in the real world, we check that the overall electricity consumption in a year in both scenarios is similar, and that is the reason why the retail payment is almost identical.

Name	Units	SFB	MFB	Office	Commercial
PR_BaselineElectricityConsumption	kWh	3.703	67.864	37.100	115.010
PR_RealElectricityConsumption	kWh	3.727	68.301	37.427	116.005

Table 24: Cost of retail electricity in both scenarios

In the analysis that we have done, the yearly benefit for the Heat Provider because of the enrolment in the FHP programme, CF_HeatProvider, is positive, so it is an added income that helps to reduce the

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energy bill. To this result, there are also two other factors which contribute, the FHP_PA_ServiceFee and the FHP_AP_IncentiveFlexibility, which are explained in the 6.3.4.1.6 section.

Name	Units	SFB	MFB	Office	Commercial
BAS_UP_ServiceFee	€	1.481	27.146	14.840	46.004
FHP_UP_ServiceFee	€	1.481	27.146	14.840	46.004
BAS_PR_RetailPayment	€	1.328	24.340	13.074	40.530
FHP_PR_RetailPayment	€	1.329	24.364	13.182	40.855
FHP_PA_ServiceFee	€	13	232	127	394
FHP_AP_IncentiveFlexibility	€	22	405	244	763
BAS_CF_HeatProvider	€	153	2.805	1.766	5.474
FHP_CF_HeatProvider	€	161	2.954	1.775	5.517
CF_HeatProvider	€	8	149	9	44

Table 25: Heat Provider cash flow

6.3.4.1.3 DER Producer

In Sweden, the objective in 2020 is to produce the 39,8% of the Gross final Energy Consumption with RES [30]. In 2012, Norway and Sweden reached a joint agreement to increase their production of electricity from renewable energy sources by 28,4 terawatt hours (TWh) by 2020, so that it would be 35.560TWh in 2020. Sweden then increased its target, with the aim of adding another 18 TWh by 2030. At the end of 2021, Sweden expects to have 10.958 MW of wind capacity, which would represent a wind energy annual production of 29.881 GWh

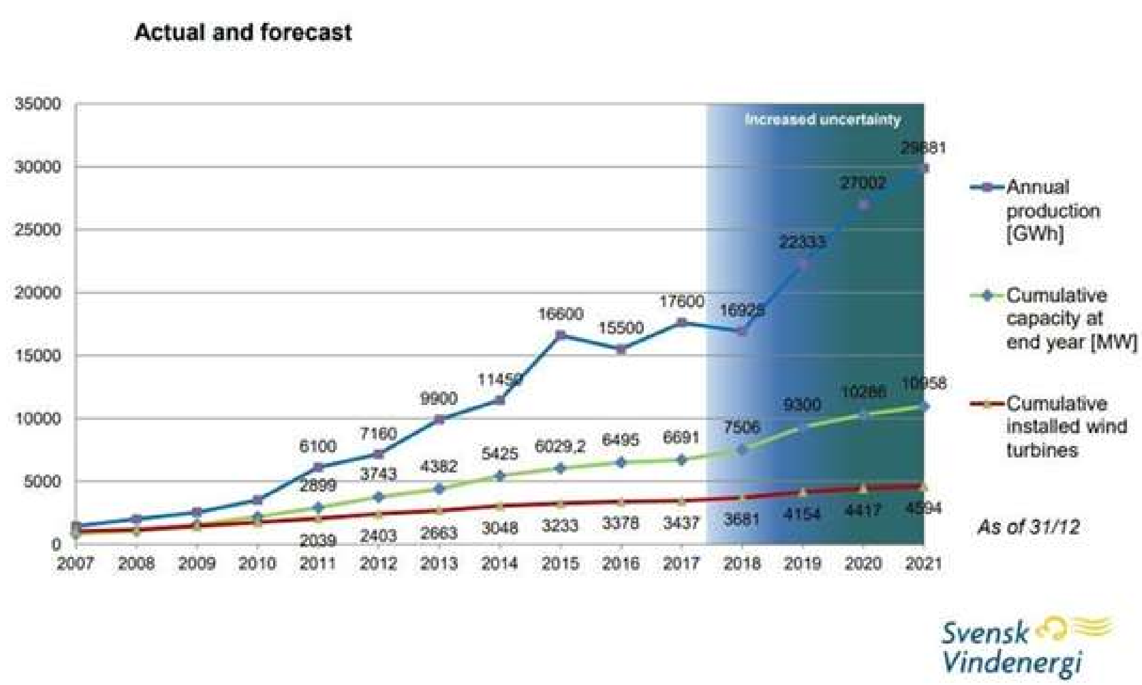

Figure 52: Sweden's energy target. Source: Swedish Energy Association

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In 2016[94] wind power plants produced 15.479 GWh and solar PV power plants produced 143 GWh. Due to this 1:10 ratio, and to the unavailability of hourly PV production data at the country level, we decide to focus the analysis of renewable production on wind energy. In 2018, at the end of the year, the country's total installed wind capacity was 7,4GW [30].

For this analysis, we base our data in real data from 2018. The gaps in the NordPool database were filled with the prognosed values, as those were all available. We used the wind production data from NordPool to set BE_PotentialElectricityProduction.

In Sweden transmission charges consists of the following fees:

- ✓ an annual capacity fee, which accounts for approximately half of revenues. The size of the capacity fee is determined in accordance with the geographical latitude. Electricity producers pay more in the North, where there is a surplus capacity of electricity production, and less in the South, where the large-scale consumers and the export markets are.
- ✓ an hourly usage fee accounts for the other half of revenues and is dependent upon the marginal transmission losses. The usage fee is calculated as the product of a marginal coefficient of loss for the connection point, the relevant input or output of energy at this point and the current price of the loss energy
- ✓ an initial connection fee, which is only brought to bear when significant investment is required in order to connect new facilities which only provide for the interests of one player, or a small number of players.

We do not have spatial information on the CBA tool on where are the producers and consumers located at the national grid, but we know that on average, transmission fees are the 40% of the payments in the energy bill of a consumer[95]. As we have considered that the price paid by the Heat User, AverageElectricityPrice, is the double of the average price that the Heat Provider pays for electricity, we set that the transmission fee is a constant value of the 20% of AverageElectricityPrice, both for producers and retailers, RT_EnergyTermPrice.

[94] http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__EN__EN0105/ElProdAr/table/tableViewLayout1/?rxid=c5513a49-9df3-46b6-9239-f66268b5f0d6

[95] The Swedish Electricity Market and the Role of Svenska Kraftnät, https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/022/42022239.pdf

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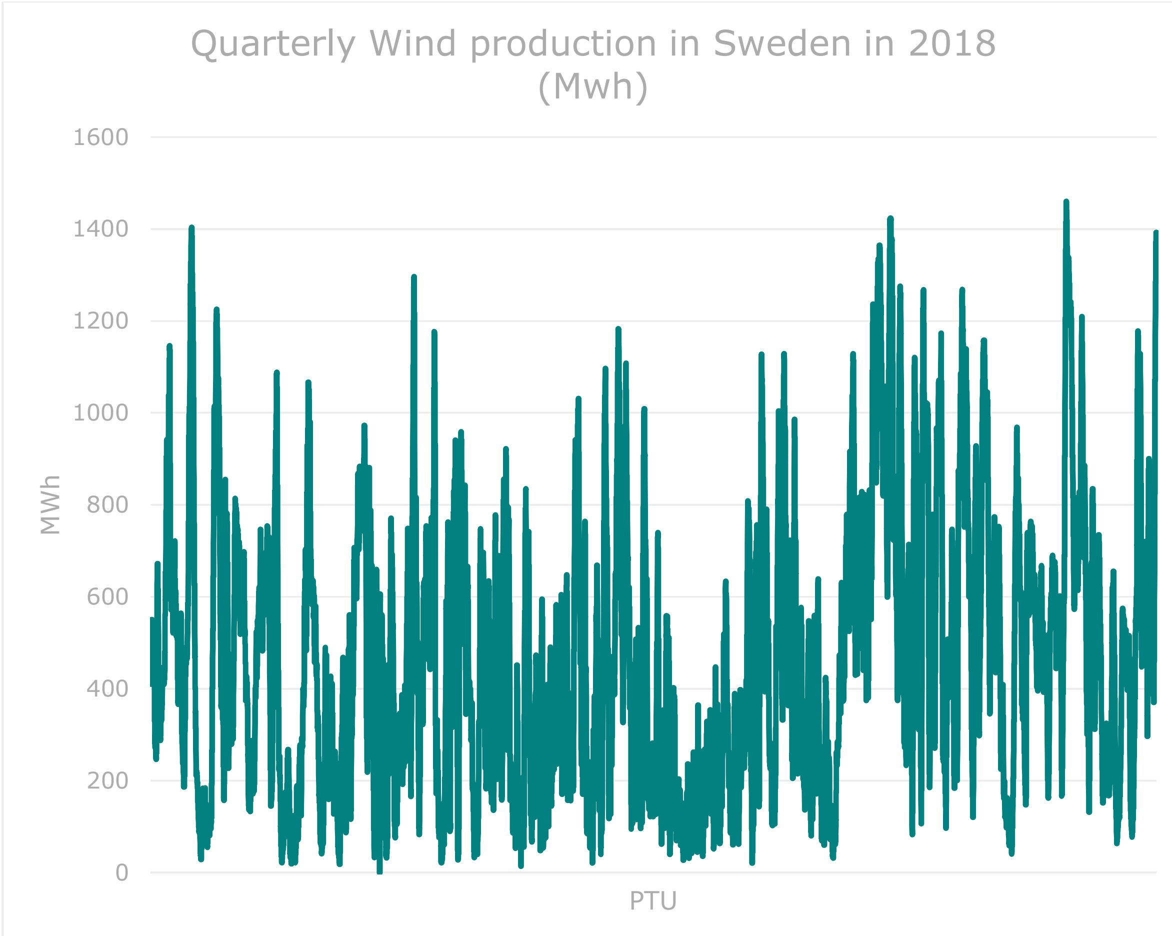

Figure 53: Wind production in Sweden in 2018

To force the assessment of the scenario with different levels of wind energy penetration, we used the profile of 2018 data scaled with a scaling factor which represents a variable capacity compared to that in 2018:

$$\text{WindScalingFactor} = \text{EB\_MaxPower}/\text{EB\_MaxPower2018}$$

Name	Units	Wind
EB_Type	Wind/PV	Wind
EB_MaxPower	kW	10.958.000
EB_MaxPower_2018	kW	7.400.000

Table 26: Max power

The government also remunerates the production to the DER Producers by their contribution to the GHG emission reduction. The incentives are regulated by law and are based on the type of technology, the installed power, the year when it came into operation, etc. This segmentation of subsidies is reflected on the premium for DER. In this analysis we consider that they are due to the DER real production.

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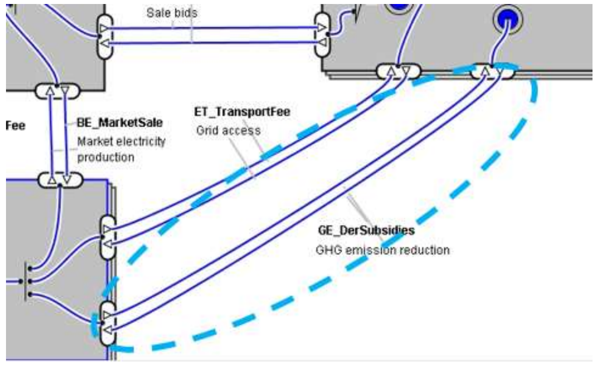

Figure 54: BAS_GE_DerSubsidies

$$BAS\_GE\_DerSubsidies_y = \sum_{q=1}^{4*8760} GE\_MarketDerSubsidies_q$$

$$GE\_MarketDerSubsidies_y = ET\_DerPremium_q * BE\_MarketElectricityProduction_q$$

Being

$$BE\_MarketElectricityProduction = BE\_PotentialElectricityProduction - BE\_InitialCommercialCurtailmentEnergy - DE\_InitialGridCurtailmentEnergy$$

In the FHP scenario the DER gets a reimbursement, as it happens in the BAS scenario, but in this case it is based on its real production. But in this case, the real production is increased because part of the initial curtailment is mitigated.

$$FHP\_GE\_DerSubsidies_y = \sum_{q=1}^{4*8760} GE\_MarketDerSubsidies_q + \sum_{q=1}^{4*8760} GE\_BilateralContractsDerSubsidies_q$$

$$GE\_BilateralContractsDerSubsidies_y = ET\_DerPremium_q * BE\_IncreasedElectricityProduction_q$$

Where

$$BE\_IncreasedElectricityProduction = BE\_InitialCommercialCurtailmentEnergy + DE\_InitialGridCurtailmentEnergy - BE\_FinalCommercialCurtailmentEnergy - DE\_FinalGridCurtailmentEnergy$$

In Sweden, as stated in section 2.9, has a DER subsidy mechanism based on green certificates. We use the price of 12,1€/MWh, as it was in 2017, for ET_DerPremium. This parameter is applied both to calculate the payment to the DER producer because of its renewable real production and to calculate the compensation that both BRP and DSO pay to the DER Producer due to commercial and grid curtailment respectively.

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Name	Units	Wind
BAS_GE_DerSubsidies	€	183.627.743
FHP_GE_DerSubsidies	€	189.713.726

Table 27: Renewable subsidies

In principle, in our business case design, the DER Producer sells its production, BE_MarketElectricityProduction, at the market by default in the BAS scenario:

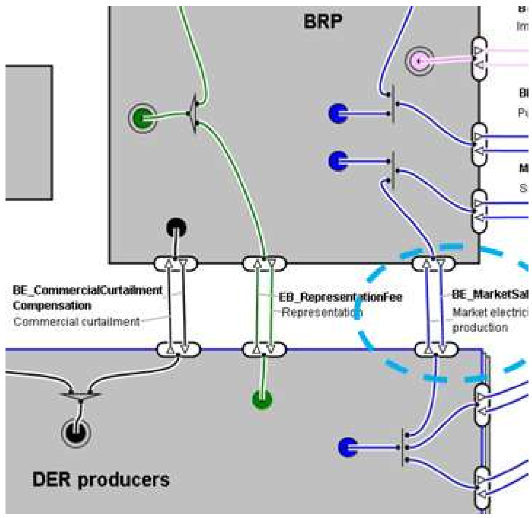

Figure 55: BAS_BE_MarketSale

$$BAS\_BE\_MarketSale_y = \sum_{q=1}^{4*8760} (RB\_DayAheadMarketPrice_q * BE\_MarketElectricityProduction_q)$$

Where:

$$BE\_MarketElectricityProduction_q = BE\_PotentialElectricityProduction_q - BE\_InitialCommercialCurtailmentEnergy_q - DE\_InitialGridCurtailmentEnergy_q$$

The potential production BE_PotentialElectricityProduction is decreased by both the grid-based and market-based curtailments, which have been assessed considering the following:

Market-based curtailment

To calculate the initial commercial curtailment, we consider that:

- ✓ The market price must be below a certain BE_CommercialCurtailmentPriceThreshold
- ✓ In case of curtailment, a percentage of the capacity is affected, BE_CommercialCurtailmentPercentage

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The BRP would curtail the DER producer because the market price would be too low, as explained in section 2.7.5. This case is covered in the UC2, SystemRESCurtailmentMitigation. It is very difficult to get real numbers on the appearances of this type of market-based curtailment in the current Swedish system, because it's part of a private business relationship between the DER producer and the BRP. We assume that if BM_DayAheadMarketPrice is lower than a certain threshold, BE_CommercialCurtailmentPriceThreshold, the BRP cannot allocate a part of its potential production BE_PotentialElectricityProduction in the market, BE_CommercialCurtailmentPercentage. This assumption will be more and more encountered as far as the penetration of renewable intermittent energy increases, and we expect that in the following years, if countermeasures are not taken, it would be one of the main reasons for renewable curtailment.

Grid-based curtailment

On the other hand, grid curtailment is driven in our UC1, LocalRESCurtailmentMitigation. In this case, this curtailment is associated to situations in which there is a lack of capacity, related to a high ratio between renewable local production a local consumption, in certain zones of the distribution grid. As we cannot reproduce the topology of the grid in this cost benefit analysis tool, the option we have chosen to mimic these situations is to decide the moments in which local grid congestions could be encountered when the parameter RenewableProductionConsumptionRatio is higher than DE_RenewableProductionConsumptionThreshold. In that case, the initial curtailment would represent all the excess of renewable production so that RenewableProductionConsumptionRatio is limited to DE_RenewableProductionConsumptionThreshold.

During 2018, grid-based curtailment was rarely executed in Sweden, based on the feedback of our DSO, so we assume that the maximum production/consumption ratio of 2018 is still affordable. From the 2018 numbers, we decide to use a DE_RenewableProductionConsumptionThreshold of 50% as the threshold for our study, because the ratio between renewable production and consumption never exceeded that value in 2018 and there was still a certain margin for avoiding congestions. With that ratio of 50%, and with the 2018 wind production, there was no grid-based curtailment, BAS_DE_GridCurtailmentCompensation = FHP_DE_GridCurtailmentCompensation = 0.

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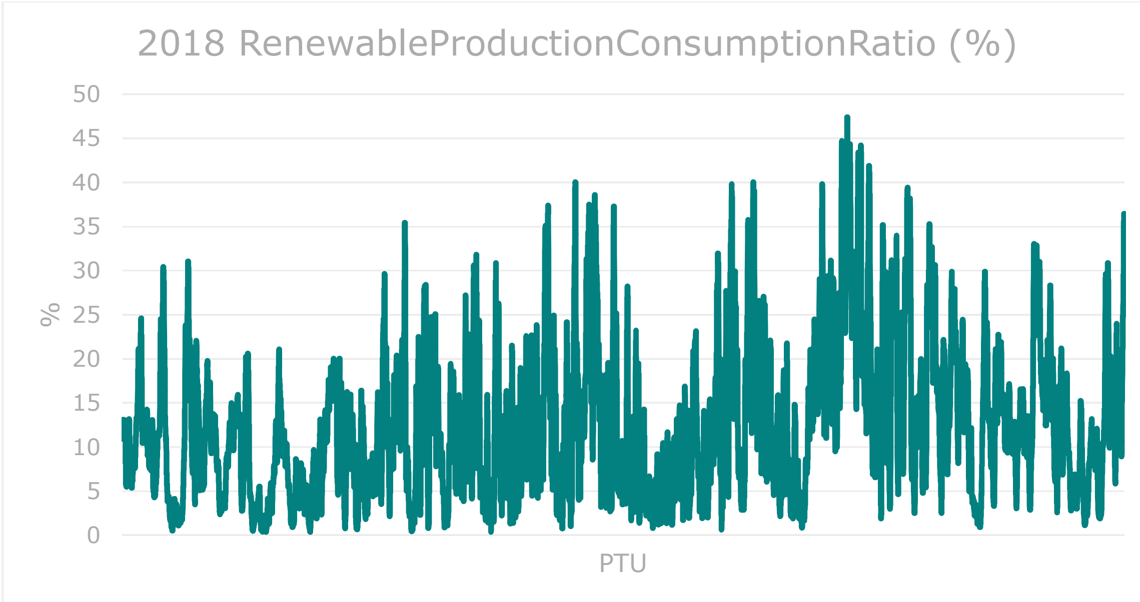

Figure 56: Renewable to production ratio. Wind data 2018

But expecting an increase of wind installed capacity, as expected for 2021 where the target is 10,98GW compared to the 7,4GW at the end of 2018, we study which would be the effect of that capacity increment keeping all the rest of the variables with the same shape and values as we use for 2018.

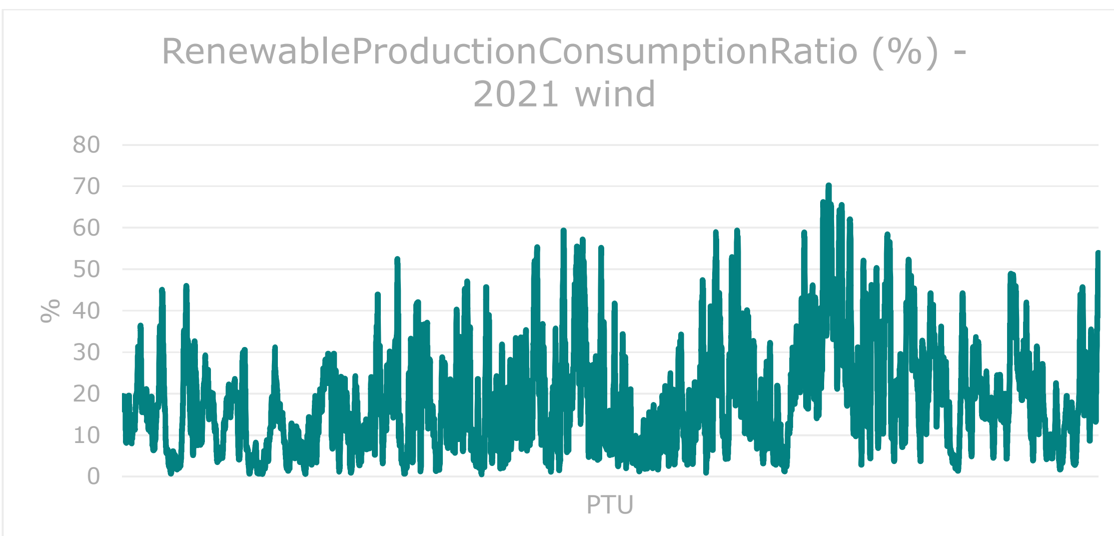

Figure 57: Renewable production to consumption ratio. Wind data 2021

If we order the data series by descending values, we can see that there are some time periods with expected congestion due to the high value of the ratio between wind production and consumption, which are represented in the left part of the curve, which follows an asymptotic behavior.

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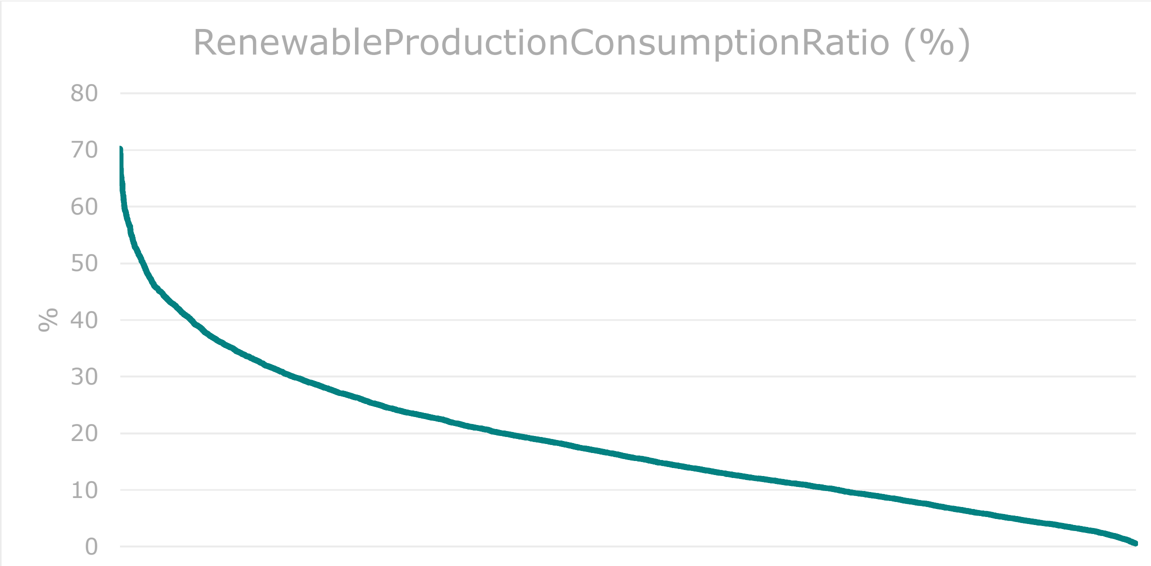

Figure 58: Ordered renewable production to consumption ratio

Given the previous considerations, and taking into account both the production increase allocated to bilateral contracts with the retailers due to the flexibility provided in UC1 and UC2, we check that the cash flow of the DER producer is not affected by the flexibility provision.

BAS_EB_RepresentationFee	€	13.149.600
FHP_EB_RepresentationFee	€	13.149.600
BAS_BE_MarketSale	€	659.733.763
FHP_BE_MarketSale	€	659.733.763
FHP_BE_BilateralContractsSale	€	13.574.256
BAS_ET_TransportFee	€	728.440.635
FHP_ET_TransportFee	€	729.062.357
BAS_EB_ImbalancePayment	€	10.175.109
FHP_EB_ImbalancePayment	€	10.175.109
BAS_BE_CommercialCurtailmentCompensation	€	11.033.367
FHP_BE_CommercialCurtailmentCompensation	€	2.610.012
BAS_DE_GridCurtailmentCompensation	€	38.931.312
FHP_DE_GridCurtailmentCompensation	€	28.316.151
BAS_GE_DerSubsidies	€	183.627.743
FHP_GE_DerSubsidies	€	189.713.726
BAS_CF_DERProducer	€	141.560.841
FHP_CF_DERProducer	€	141.560.842
CF_DERProducer	€	0

Table 28: Heat Provider cash flow

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The reason behind this is that, as we will explain in sections 6.3.4.1.4.1 6.3.4.1.5.1 we assume that both the DSO and the BRP fully compensate to the DER Producer in case of grid or commercial curtailment respectively.

6.3.4.1.4 DSO

6.3.4.1.4.1 LocalRESCurtailmentMitigation

The exchange between the Aggregator and the DSO about negotiation phase flexibility is billed depending on the prices of the flexibility market managed by the DSO. These prices are offered by the aggregator when the flexibility offer is sent to the DSO, and the DSO decides if it accepts them or not. Flexibility is paid by the DSO for each kWh contracted by the DSO to the aggregator. Contracted flexibility will be verified with real measurements, so that just verified flexibility will be reimbursed.

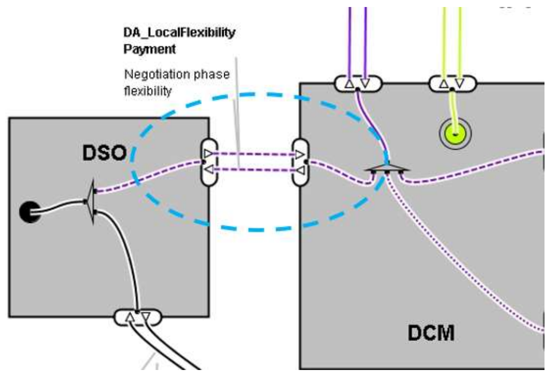

Figure 59: FHP_DA_LocalFlexibilityPayment

$$DA\_LocalFlexibilityPayment_y = \sum_{q=1}^{4*8760} (DA\_LocalFlexibilityPrice_q * DA\_LocalFlexibilityEnergy_q)$$

being DA_LocalFlexibilityEnergy the planned flexibility that the Heat Providers in the portfolio of the aggregator provide upon agreement. To calculate this, first we calculate the max flex that the whole portfolio of the aggregator can provide, DA_PotentialLocalFlexibilityEnergy .

$$DA\_PotentialLocalFlexibilityEnergy = \sum_{q=1}^{4} PR\_PotentialModifiedElectricityConsumptionUC1 * Number\ HeatProvidersTypeQ$$

Where PR_PotentialModifiedElectricityConsumptionUC1 is the maximum flexibility that could provide each Heat Provider, in case that in the BAS scenario the DSO needs to curtail for that time unit:

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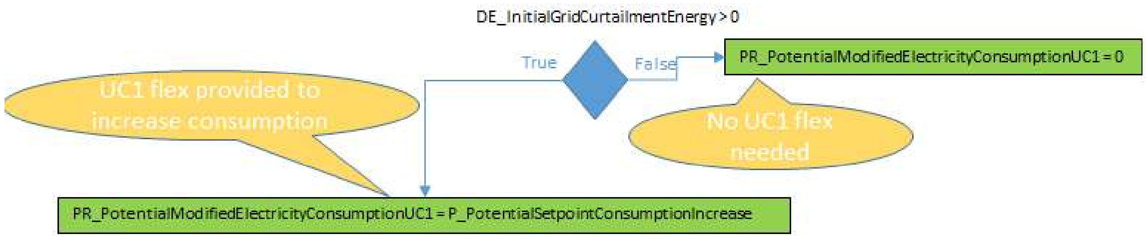

Figure 60: PR_PotentialModifiedElectricityConsumptionUC1

The flexibility that the Heat Provider can provide, to increase its consumption, depends on the current capacity of its thermal inertia and is limited by the amount of energy that can be increased from its baseline to its contracted power. This potential flexibility calculation is shared also with UC2 and UC3, and in case that the UC1 does not use, it is available for being use in UC2, and if not, in UC3 (following the use case prioritization rules).

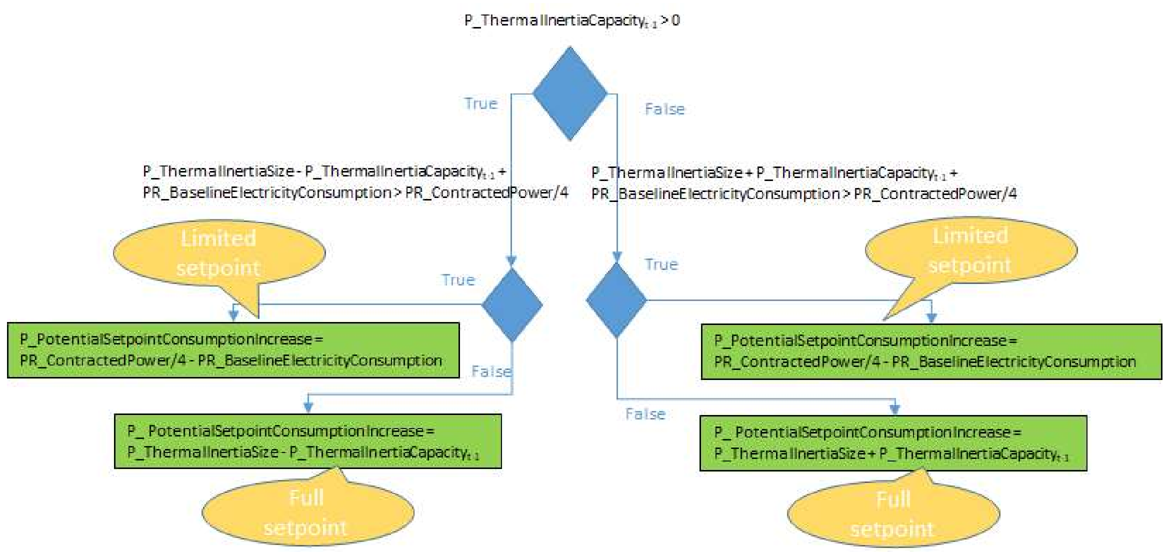

Figure 61: P_PotentialSetpointConsumptionIncrease

DA_PotentialLocalFlexibilityEnergy has been calculated it is limited by the value of DE_InitialGridCurtailmentEnergy to calculate DA_LocalFlexibilityEnergy so that the aggregator limits the flexibility provided to that requested by the DSO.

$$DA\_LocalFlexibilityEnergy = min(DA\_PotentialLocalFlexibilityEnergy, DE\_InitialGridCurtailmentEnergy)$$

Finally, the limitation is propagated backwards to calculate the real flexibility provided by each Heat Provider:

$$PR\_ModifiedElectricityConsumptionUC1 = PR\_PotentialModifiedElectricityConsumptionUC1 * DA\_LocalFlexibilityEnergy \ / \ DA\_PotentialLocalFlexibilityEnergy$$

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Avoiding curtailment of renewable energy production due to distribution grid constraints violations (grid curtailment) would require investing in upgrading the capacity in the DSO network, which would be very costly. Besides, if we consider that this action would be executed for few hours annually, it is understandable that DSOs would prefer to compensate DER Producers for their losses in energy production. The possible compensation would be based on market prices and/or subsidies. Two possible schemes could be used for grid curtailment, voluntary or involuntary.

DER Producers can accept voluntary curtailment in their contracts related to the grid connection, due to grid constraints. By this acceptance, DER Producers could have a discount on the initial connection charges at the moment of connection to the grid. This case applies mostly when the DER Producer directly or indirectly finances the connection lines to the network and accepts to be curtailed due to a constraint in its own connection cable. Then the DER Producer must decide if it prefers to install a higher capacity cable, and avoid the curtailment, or the contrary. Obviously, there is no compensation for this kind of curtailment, and it is considered out of scope of the FHP project studies.

Involuntary curtailment can take place temporarily due to delays in infrastructure investment relative to generation capacity, due to the slower pace of network retrofit compared to renewable penetration rate. In this case, the network owner (DSO) would be obligated to compensate the generator at least partly for the loss incurred. The costs of curtailment would be settled in terms of lost generation (grid curtailment energy), based on the kind of remuneration that the DER Producer would have obtained. In the FHP business model, we assume that the incomes that the DER Producer gets are based on market prices complemented with GHG subsidies, so the compensation will be proportional to these incomes. The multiplying factor (grid curtailment factor) would be regulated depending on the national legislation.

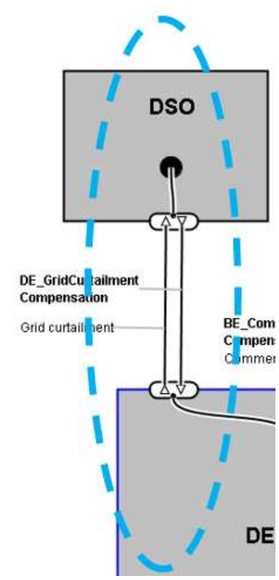

Figure 62: BAS_DE_GridCurtailmentCompensation

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$$BAS\_DE\_GridCurtailmentCompensation_y = \sum_{q=1}^{4*8760} DE\_InitialGridCurtailmentCompensation_q$$

Where

$$DE\_InitialGridCurtailmentCompensation_q = DE\_InitialGridCurtailmentEnergy_q * DE\_GridCurtailmentFactor * (ET\_DerPremium_q + BM\_DayAheadMarketPrice_q)$$

The energy to be curtailed is the excess of production compared to the production/consumption threshold:

If RenewableProductionConsumptionRatio > DE_RenewableProductionConsumptionThreshold

$$DE\_InitialGridCurtailmentEnergy_q = BE\_PotentialElectricityProduction - (RenewableProductionConsumptionRatio * DE\_RenewableProductionConsumptionThreshold * 100)$$

else

$$DE\_InitialGridCurtailmentEnergy_q = 0$$

$$FHP\_DE\_GridCurtailmentCompensation_y = \sum_{q=1}^{4*8760} DE\_FinalGridCurtailmentCompensation_q$$

Where:

$$DE\_FinalGridCurtailmentCompensation_q = DE\_FinalCommercialCurtailmentEnergy_q * DE\_GridCurtailmentFactor * (ET\_DerPremium_q + BM\_DayAheadMarketPrice_q)$$

The DSO participates as the leading role requesting flexibility in UC1, using flexibility as an alternative way to execute DER curtailment to avoid the risk of local congestion. Currently, in the Swedish scenario, the DSO does not pay any compensation to the DER producer when DERs are curtailed due to grid constraints, as during the connection permission request procedure DER producers just get granted permissions limited to the local grid capacity in the worst possible situation, when local demand is the lowest and local production the highest.

Nevertheless, we expect that in the future this obstacle to renewable capacity deployment will be overcome when the DSO has the chance to act on local demand to avoid temporary situation of congestion due to a high ratio of local production and demand. In this scenario, the government would promote the renewable capacity growth and thus provide the economic means to the DSOs to either reinforce the grid or to accomplish the consequences of not doing so, either fully compensating DERs when curtailment is needed and/or paying for local demand increase to mitigate curtailment.

As a reference, Svenska kraftnät, the TSO is investing around 600-1500 million SEKs (56-140 million euros) in transmission system reinforcement each year [72]:

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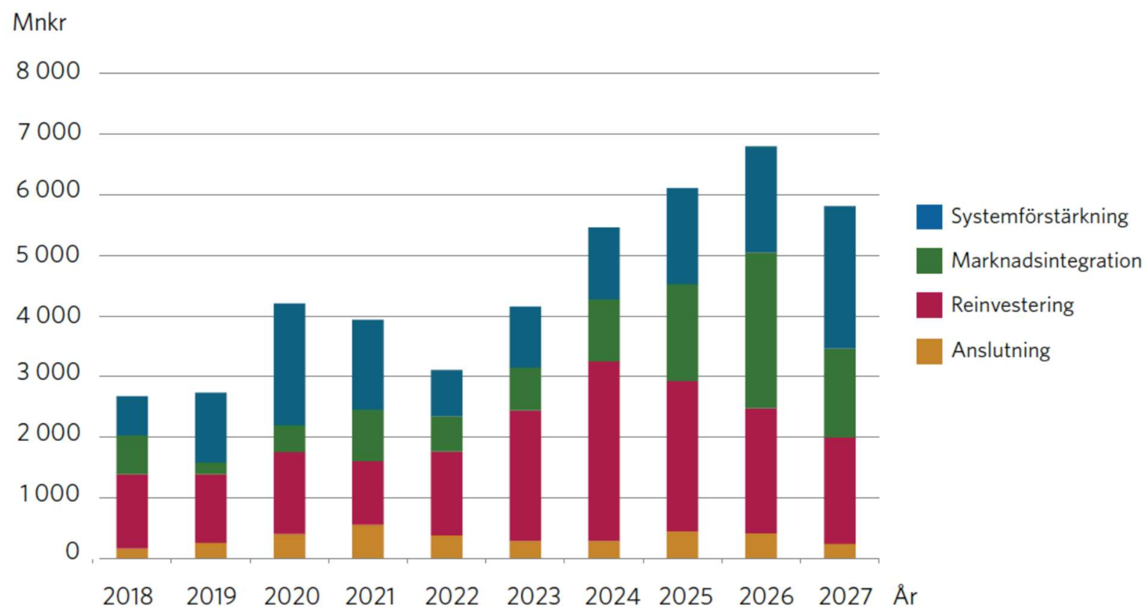

Figure 63: Investments in transmission reinforcement. Source: Swedish Energy Markets Inspectorate

Therefore, we set:

$$DE\_GridCurtailmentFactor = 1$$

In our analysis we force the wind installed capacity to the 2021 objective, to check how the system would be operated in the near future without reinforcing the grid. If the consumption remains the same, in those conditions the DSO would have to pay DE_InitiallGridCurtailmentCompensation as compensation for grid curtailment, for the DE_InitialGridCurtailmentEnergy that would have to be curtailed (for an annual wind production BE_PotentialElectricityProduction, so a curtailment ratio of InitialCurtailmentRatio).

BE_PotentialElectricityProduction	kWh	16.448.920.000
DE_InitialGridCurtailmentEnergy	kWh	905.889.479
InitialCurtailmentRatio	%	5,51
DE_InitiallGridCurtailmentCompensation	€	38.931.312

Table 29: Initial grid curtailment

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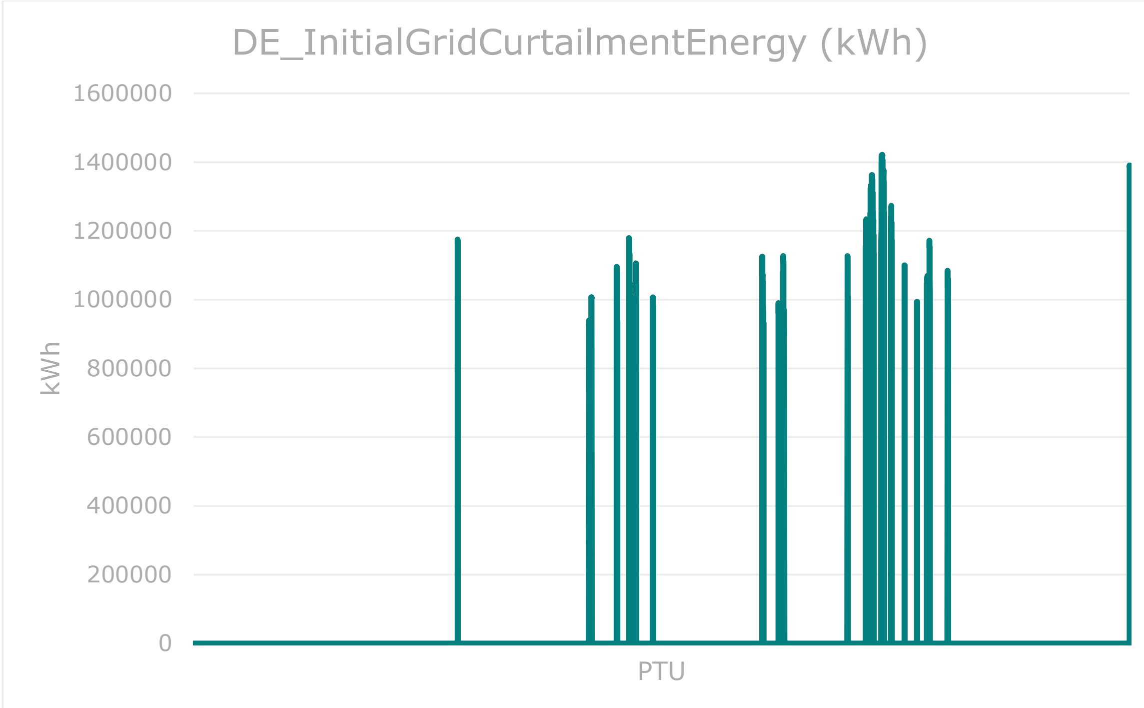

Figure 64: Initial curtailment

Given the calculation of the flexibility provided by the Heat Provider, as explained in the 6.3.4.1.2 section, we get that the flexibility that the Heat Providers can provide to increase their consumption, DA_LocalFlexibilityEnergy, which implies a final curtailment ratio of FinalCurtailmentRatio.

DA_PotentialLocalFlexibilityEnergy	kWh	560.369.841
DA_LocalFlexibilityEnergy	kWh	234.724.380
DE_FinalGridCurtailmentEnergy	kWh	671.165.099
FinalCurtailmentRatio	%	4,08
DE_FinalGridCurtailmentCompensation	€	28.316.151
FHP_DA_LocalFlexibilityPrice	c€/kWh	4,07
FHP_D_TargetBenefitMargin	%	10

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Table 30: Final grid curtailment

This is the shape of the potential flexibility that the aggregator could provide in the time periods in which the DSO asks for flexibility:

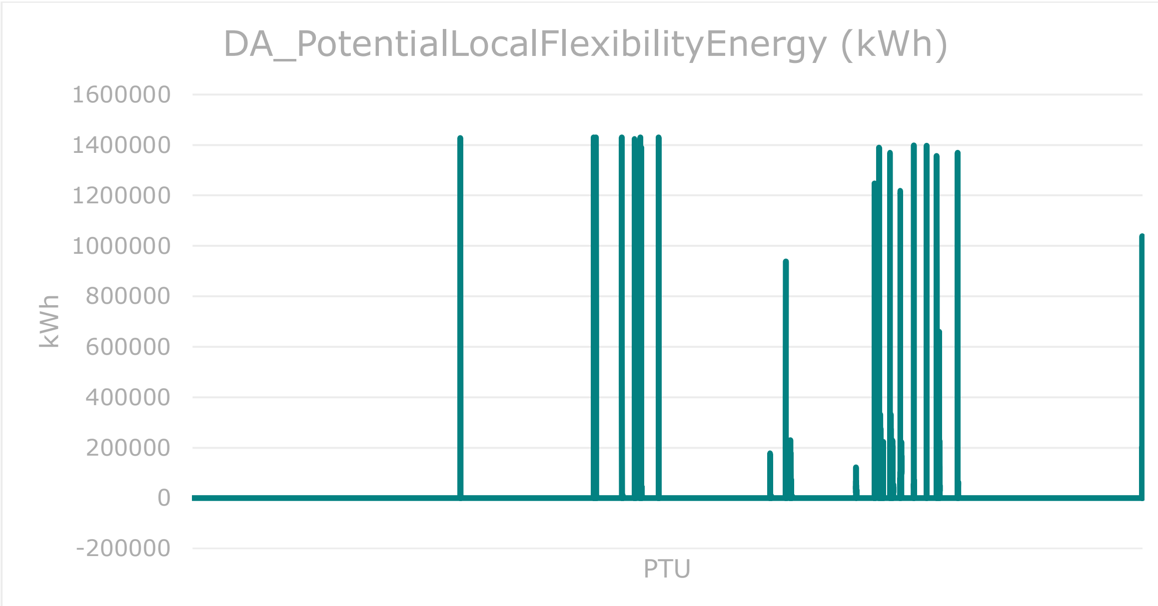

Figure 65: Potential local flexibility

And this is the shape of the flexibility that the agrees with the DSO:

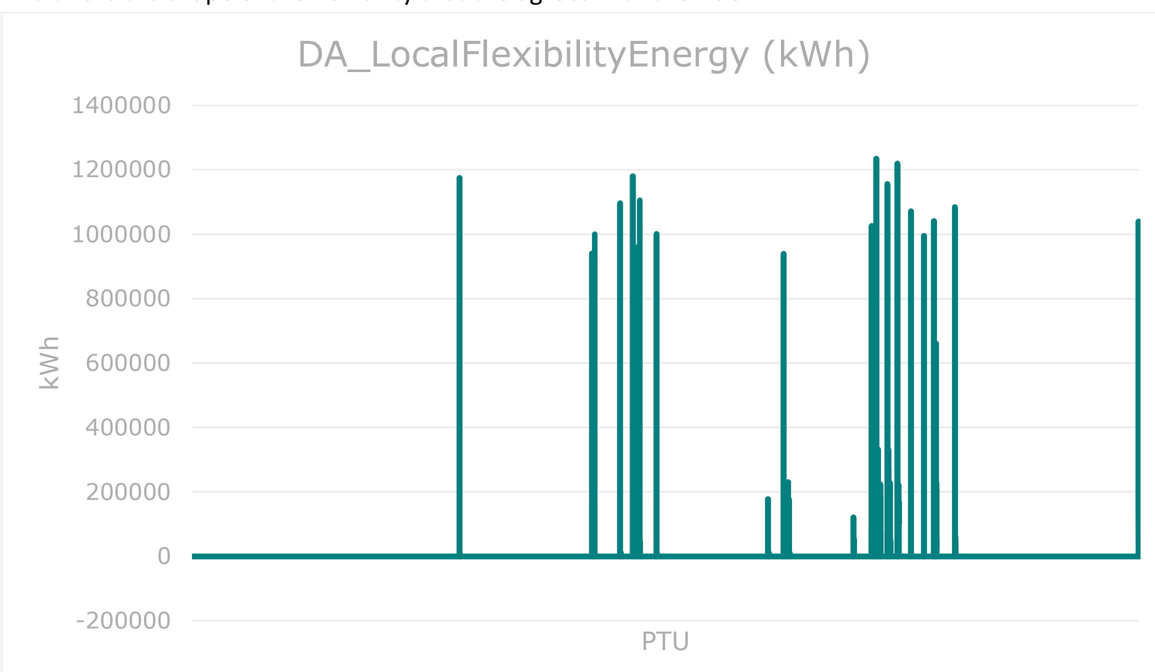

Figure 66: Local flexibility provided

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The comparison of the flexibility needs, the potential and the agreement are this:

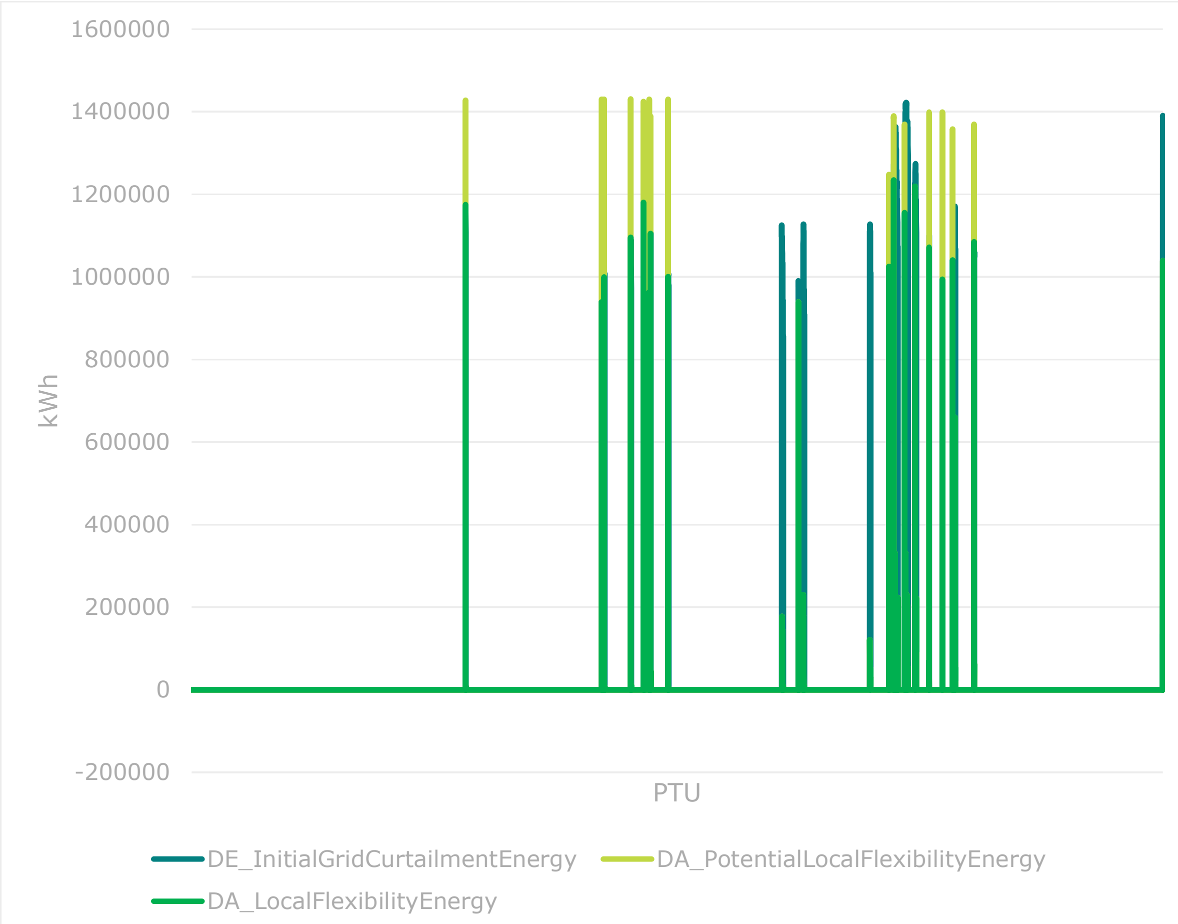

Figure 67: Initial curtailment vs potential local flexibility vs local flexibility

We can observe that under these conditions the flexibility provided by the aggregator is sometimes limited by the thermal inertia of the Heat Providers. For instance, in the following figure we can see that despite the need for flexibility of the DSO continues for several time periods, the aggregator just can provide flexibility in alternate time periods. The reason is that the capacity of the thermal inertia of the Heat Providers is next to the upper limit, and after providing all the available flexibility for consumption increase of the DSO, in the next time periods the Heat Provider just can save to consume its baseline, which is precisely the flex that it provides in the following PTU. This is the reason why the flexibility provided follows this small spike profile from there on.

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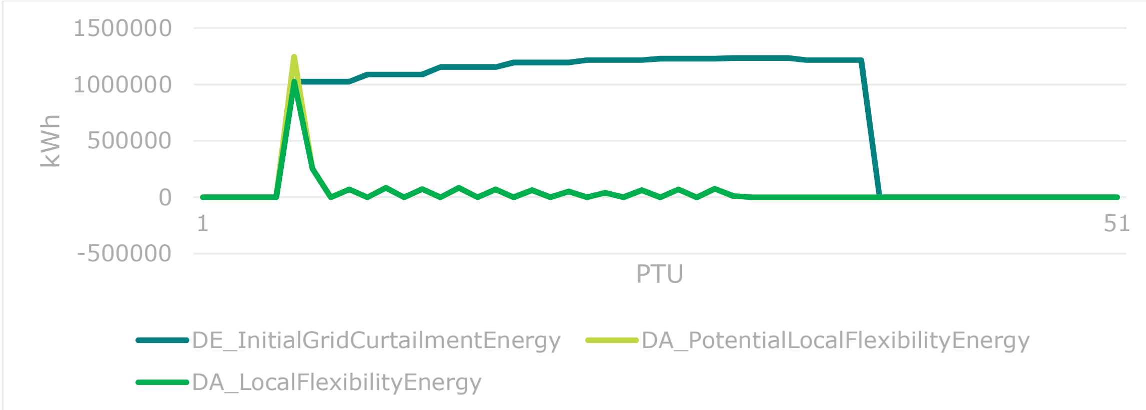

Figure 68: Initial curtailment vs potential local flexibility vs local flexibility. PTUs from 25150 to 25200

The following figure represents the evolution of both the baseline and the real consumption of a Heat Provider type 1, in the commented time units, to validate the related behaviour.

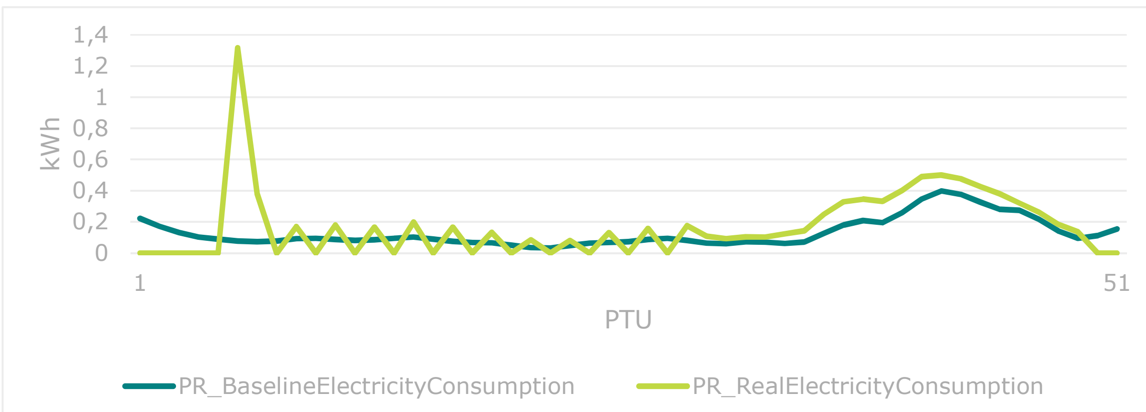

Figure 69: Real vs baseline consumption. PTUs from 25150 to 25200

As explained, the flexibility provided by the aggregator is not much limited by the flexibility requested by the DSO, being DA_PotentialLocalFlexibilityEnergy nearly DA_LocalFlexibilityEnergy, so Heat Providers provide almost always as much flexibility as they can.

Given the curtailment avoided, the final curtailment is DE_FinalGridCurtailmentEnergy. With this final curtailment the DSO would still have to pay to the DER Producers a FHP_DE_GridCurtailmentCompensation , instead of the original BAS_DE_GridCurtailmentCompensation. That means that the DSO has saved some money that can be used to pay to the aggregator for the flexibility service. The DSO would be obligated by the government to prioritise using flexibility to avoid renewable curtailment, and the DSO would also want to apply a certain benefit margin FHP_D_TargetBenefitMargin because of the risk of activating flexibility, so we calculate the Price that the DSO would be willing to pay for flexibility considering this factor.

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This gives that the DSO could pay to the aggregator an average flat Price for flexibility, FHP_DA_LocalFlexibilityPrice.

	Units	Value
FHP_DA_LocalFlexibilityPrice	c€/kWh	4,07
FHP_D_TargetBenefitMargin	%	10
BAS_DE_GridCurtailmentCompensation	€	38.931.312
FHP_DE_GridCurtailmentCompensation	€	28.316.151
FHP_DA_LocalFlexibilityPayment	€	9.553.645
BAS_CF_DSO	€	-38.931.312
FHP_CF_DSO	€	-37.869.796
CF_DSO	€	1.061.516

Table 31: Cash flow of the DSO

6.3.4.1.5 BRP

We assume that for simplicity a unique BRP represents all the national producers/consumers and the data from producers and consumers has been taken from the Nordpool market[96], for those producers and consumers in Sweden, both for real measured values and for the prognosis used to buy and sell the energy in the market.

6.3.4.1.5.1 SystemRESCurtailmentMitigation

Commercial curtailment, as covered in UC2, can occur due to market design, when DER Producers face the risk that their sale bids are not accepted by the market operator. In those circumstances, there is not enough demand in the energy market, when considering system operational restrictions for security of supply, i.e. a combination of low demand, excess of renewable production and technical minima of plants ("must-run" obligations of nuclear od combined cycle plants) which might lead to system security issues.

This use case is analysed once after grid curtailment has been assessed, as indicated in the prioritization of the use cases made for this analysis.

[96] https://www.nordpoolgroup.com/historical-market-data/

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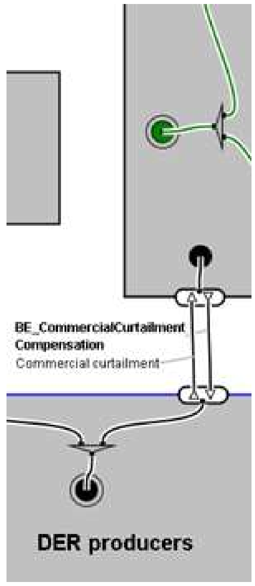

Figure 70: BAS_DE_CommercialCurtailmentCompensation

Curtailment compensation schemes are needed in order to limit market risk and thus ensure technology financing costs are not disproportionate. Compensation should be related to the foregone revenue (lost opportunity), so as in the case of grid curtailment due to grid constraints, related to the market prices and the GHG subsidies.

$$BAS\_BE\_CommercialCurtailmentCompensation_y = \sum_{q=1}^{4*8760} BE\_InitialCommercialCurtailmentCompensation_q$$

Where

$$BE\_InitialCommercialCurtailmentCompensation_q = BE\_InitialCommercialCurtailmentEnergy_q * BE\_CommercialCurtailmentFactor * (ET\_DerPremium_q + BM\_DayAheadMarketPrice_q)$$

The energy to be curtailed is the energy (potential renewable production minus the initially curtailed by grid constraints) that the BRP cannot allocate in the market:

If BM_DayAheadMarketPrice < BE_CommercialCurtailmentPriceThreshold

$$BE\_InitialCommercialCurtailmentEnergy_q = (BE\_PotentialElectricityProduction - DE\_InitialCommercialCurtailmentEnergy_q) * \mathrm{BE\_CommercialCurtailmentPercentage} * 100)$$

else

$$BE\_InitialCommercialCurtailmentEnergy_q = 0$$

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$$FHP\_BE\_CommercialCurtailmentCompensation_y = \sum_{q=1}^{4*8760} BE\_FinalCommercialCurtailmentCompensation_q$$

Where

$$BE\_FinalCommercialCurtailmentCompensation_q = BE\_FinalCommercialCurtailmentEnergy_q * BE\_CommercialCurtailmentFactor * (ET\_DerPremium_q + BM\_DayAheadMarketPrice_q)$$

The exchange between the Aggregator and the BRP about negotiation phase flexibility is also billed depending on the prices freely agreed between BRP and the aggregator in the flexibility negotiation phase.

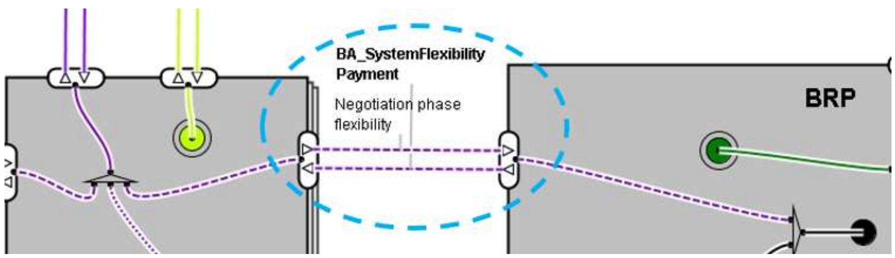

Figure 71: FHP_BA_SystemFlexibilityPayment

$$BA\_SystemFlexibilityPayment_y = \sum_{q=1}^{4*8760} (BA\_SystemFlexibilityPrice_q * BA\_SystemFlexibilityEnergy_q)$$

being BA_SystemFlexibilityEnergy the planned flexibility that the Heat Providers in the portfolio of the aggregator provide upon agreement. To calculate this, first we calculate the max flex that the whole portfolio of the aggregator can provide, BA_PotentialSystemFlexibilityEnergy .

$$BA\_PotentialSystemFlexibilityEnergy = \sum_{q=1}^{4} PR\_PotentialModifiedElectricityConsumptionUC2 * Number\ HeatProvidersTypeQ$$

Where PR_PotentialModifiedElectricityConsumptionUC2 is the maximum flexibility that could provide each Heat Provider, depending on the current capacity of its thermal inertia and limited by its contracted power. Consider that due to the prioritization of use cases in this CBA analysis, flexibility just can be provided in UC2 if it has not been provided in UC1:

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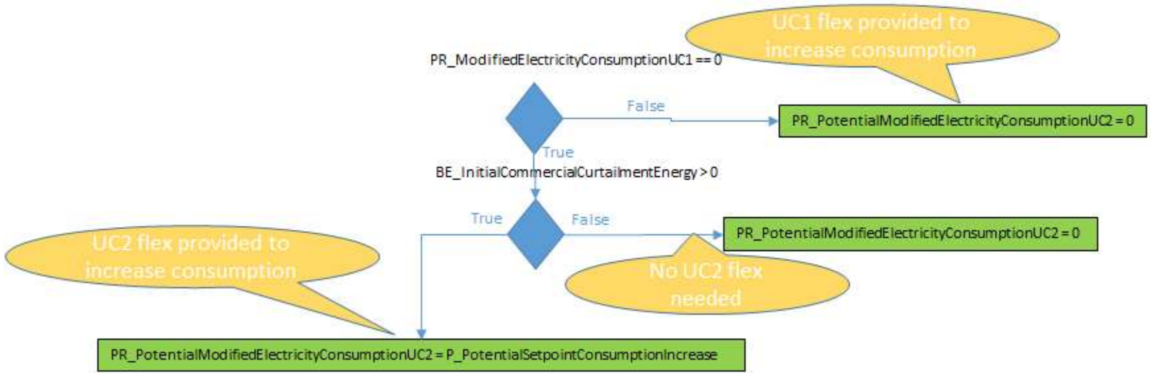

Figure 72: PR_PotentialModifiedElectricityConsumptionUC2

Once BA_PotentialSystemFlexibilityEnergy has been calculated it is limited by the value of DE_InitialCommercialCurtailmentEnergy to calculate BA_SystemFlexibilityEnergy so that the aggregator limits the flexibility provided to that requested by the BRP.

$$BA\_SystemFlexibilityEnergy = min(BA\_PotentialSystemFlexibilityEnergy, DE\_InitialCommercialCurtailmentEnergy)$$

Finally, the limitation is propagated backwards to calculate the real flexibility provided by each Heat Provider:

$$PR\_PotentialModifiedElectricityConsumptionUC2 = PR\_PotentialModifiedElectricityConsumptionUC2 * BA\_SystemFlexibilityEnergy \; / \; BA\_PotentialSystemFlexibilityEnergy$$

The BRP is the party requesting flexibility in UC2, in order to avoid system level renewable curtailment. The BRP represents all the DER producers in our analysis, in which we consider just wind energy producers. Between the DER producer and the BRP there is a commercial contract that binds the BRP to sell all the production of the DER Producer at the market. This obligation implies a risk, because sometimes the BRP will not be able to allocate that production due to the reasons mentioned for market-based curtailment, and in case that occurs the BRP must compensate to the DER Producer due to the lost opportunity of not selling its production. Up to what point the BRP must compensate to the DER producer is decided by both parties. The BRP is internalizing the risk of not being able to sell the producer's energy and because of that it would calculate that risk and allocate a fund to cover it. At the end of the day, the BRP is a commercial party that want to get a profit margin based on a risk assessment and given the number of that risk assessment it will decide a reasonable price to cover it. That price dictates the incomes for the BRP and is translated to the price of the service fee that it requests to the composers of its portfolio, UP_YearlyServiceFee. With that income, the BRP will both have to pay the imbalances to the TSO and the compensations for curtailment to the DER producers and get a commercial margin for its activity. In conclusion, the highest the risk assumed by the BRP the higher the service fee will be. In order to favour the competitive advantage of the BRP we consider that for the DER producer it will be crucial to assure its incomes despite of the market conditions, so we bet for a fully compensation formula. Therefore, we set:

$$DE\_CommercialCurtailmentFactor \; = \; 1$$

We have analysed the market prices in 2018, to define BE_CommercialCurtailmentPriceThreshold.

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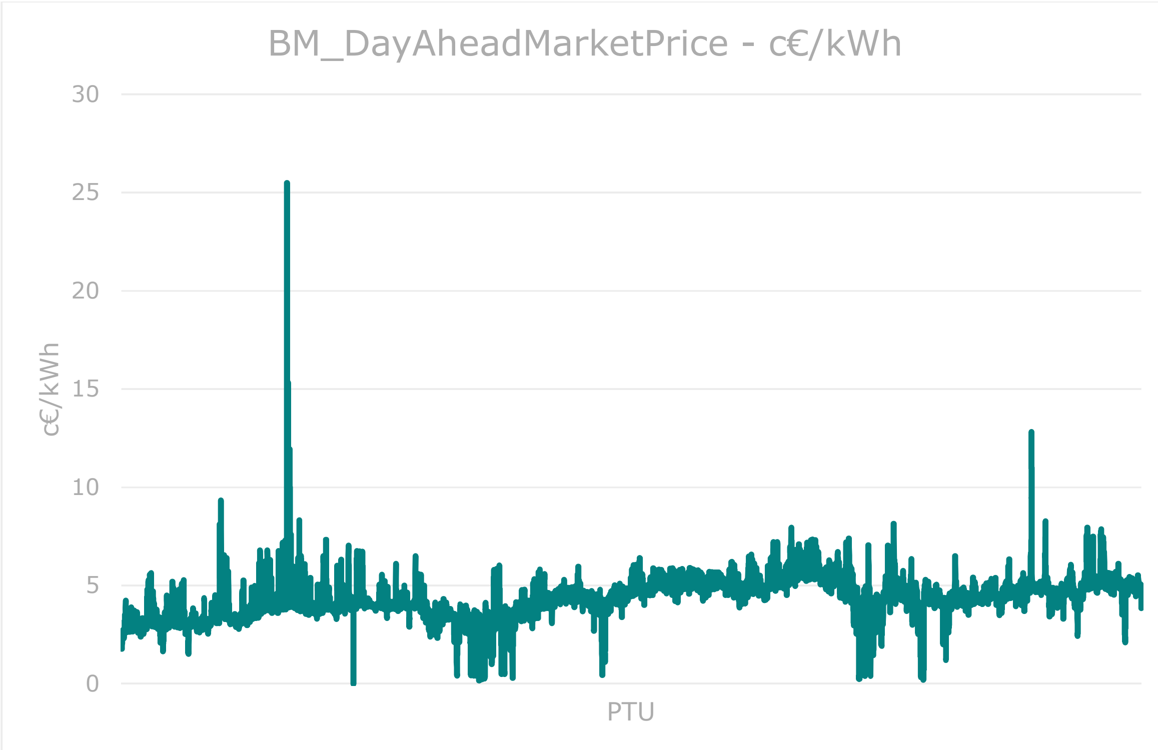

Figure 73: Spot market prices

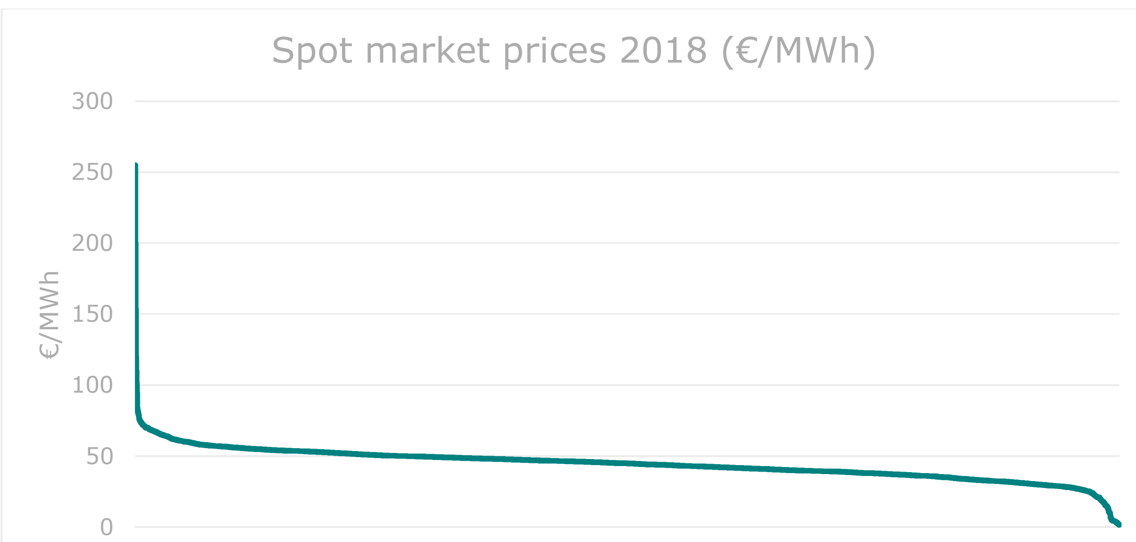

Figure 74: Spot market prices. Descending order

We can see clearly that there are three price ranges. There are a few time units with very high prices (over 60€/MWh), a normal range between 60€/MWh and something around 25€/MWh, and some points below that threshold. We calculate that threshold accurately, and we get the value of 26,77€/MWh. This price represents the price below which we assume there are distorted market conditions and the BRP could have problems to allocate the DER production.

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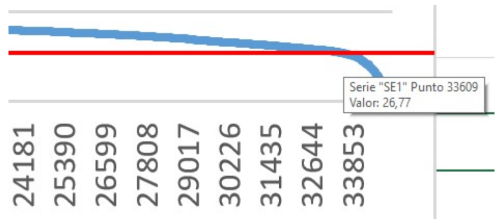

Figure 75: BE_CommercialCurtailmentPriceThreshold calculation

Name	Units	Wind
BE_CommercialCurtailmentPriceThreshold	c€/kWh	2,677

Table 32: BE_CommercialCurtailmentPriceThreshold

In these situations, it is very difficult to estimate which could be the percentage of renewable production that the BRP could not allocate, because this information is confidential between the two parties involved in the commercial arrangement, the DER producer and the BRP, and we have not been able to find it. Due to that, we create an artificial estimation of BE_CommercialCurtailmentPercentage, being the 50%.

In those conditions the BRP would have to pay BE_InitiallCommercialCurtailmentCompensation as compensation for commercial curtailment, for the BE_InitialCommercialCurtailmentEnergy that would have to be curtailed (for an annual wind production BE_PotentialElectricityProduction, so a curtailment ratio of InitialCurtailmentRatio).

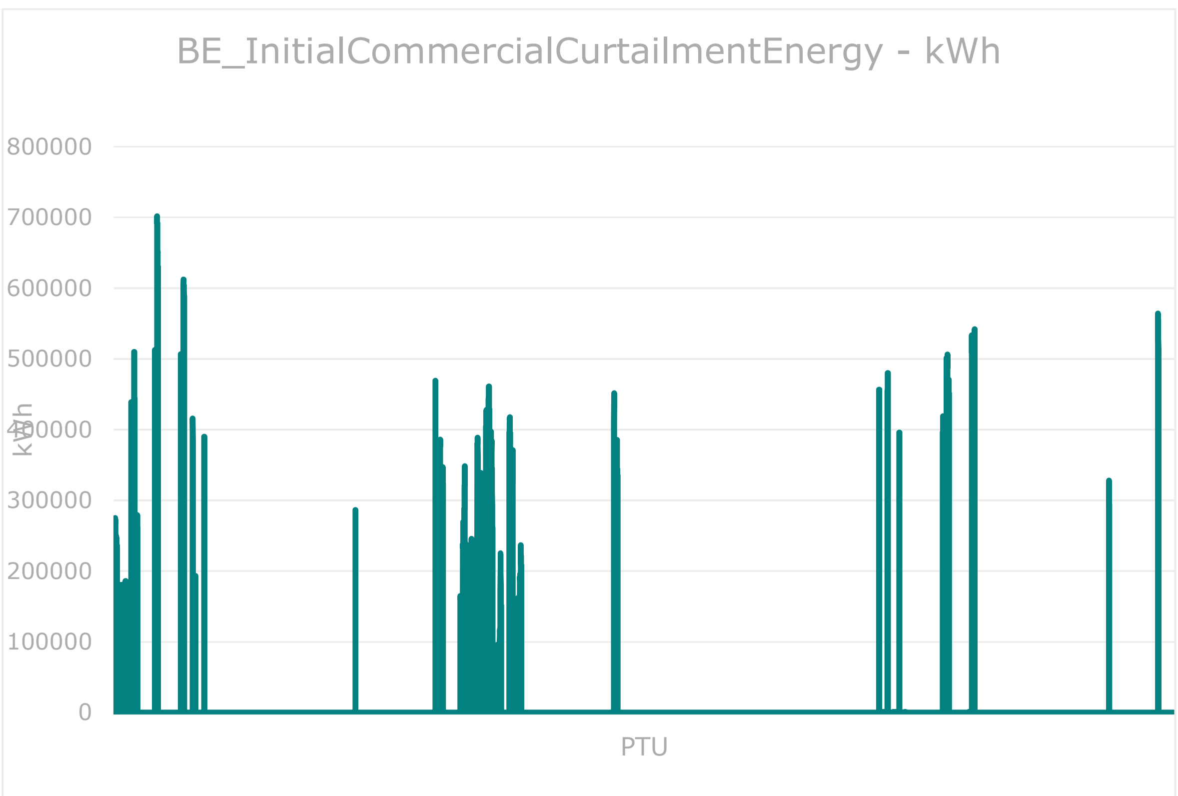

Figure 76: Initial curtailment

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BE_PotentialElectricityProduction	kWh	16.448.920.000
BE_InitialCommercialCurtailmentEnergy	kWh	367.183.960
InitialCurtailmentRatio	%	2,23
BE_InitiallCommercialCurtailmentCompensation	€	11.033.367

Table 33: Initial commercial curtailment

Given the calculation of the flexibility provided by the Heat Provider, we get that the flexibility that the Heat Providers could provide to increase their consumption, DA_PotentialSystemFlexibilityEnergy , and the flexibility that they already provide, DA_SystemFlexibilityEnergy.

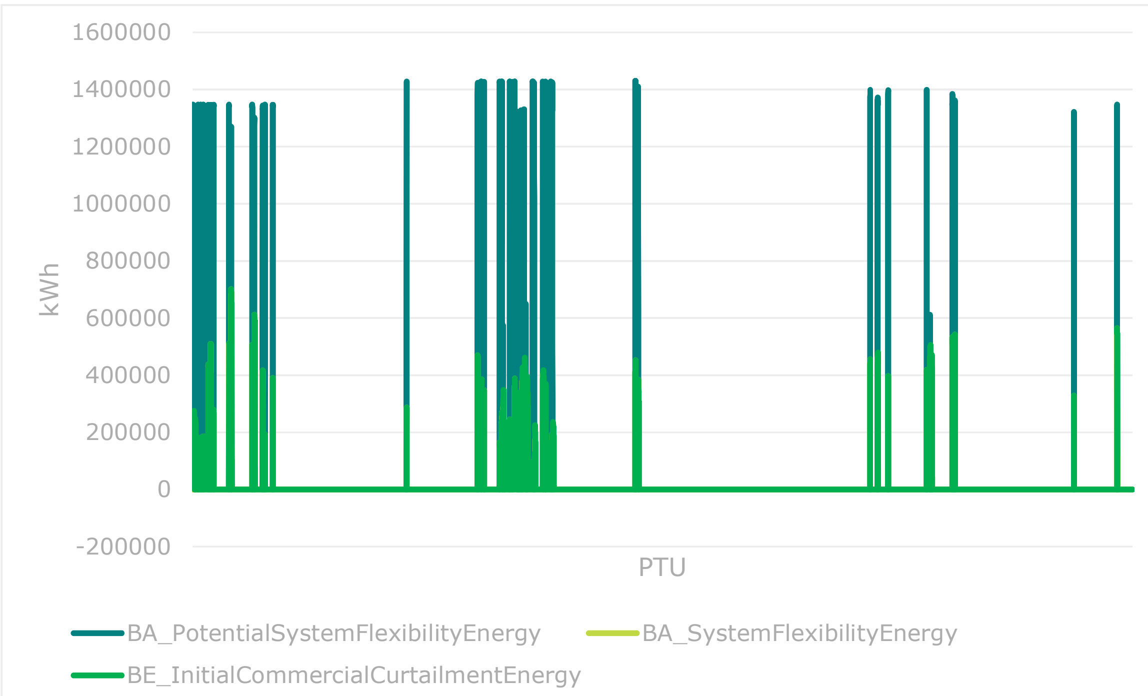

Figure 77: Flexibility needed vs potential vs provided

With this curtailment avoided, we calculate the final curtailment ratio FinalCurtailmentRatio.

DA_PotentialSystemFlexibilityEnergy	kWh	2.605.745.836
DA_SystemFlexibilityEnergy	kWh	268.249.378
BE_FinalCommercialCurtailmentEnergy	kWh	98.934.583
FinalCurtailmentRatio	%	0,60
BE_FinalCommercialCurtailmentCompensation	€	2.610.012
FHP_BA_SystemFlexibilityPrice	c€/kWh	3,14
FHP_B_TargetBenefitMargin	%	10

Table 34: Final commercial curtailment

In this case, the flexibility that the Heat Providers can offer is much higher than that that the BRP requests, as there is a big difference between BA_PotentialSystemFlexibilityEnergy and BA_SystemFlexibilityEnergy.

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For instance, zooming in the 100 first 15min periods of the year, we appreciate also the thermal capacity saturation effect that will be explained in detail in the DSO section, when the flexibility is provided in alternating periods as soon as flexibility is available after the recovery of capacity due to baseline saving.

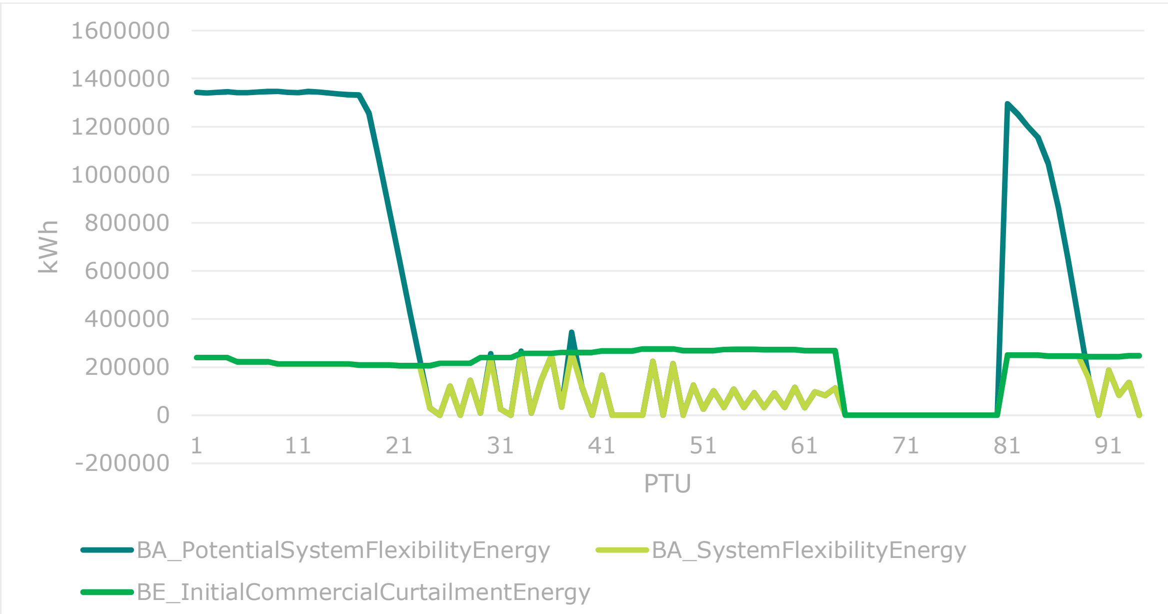

Figure 78: Flexibility needed vs potential vs provided during the first 100 PTUs

Given the final curtailment, BE_FinalCommercialCurtailmentEnergy , the BRP would still have to pay to the DER Producers a FHP_BE_CommercialCurtailmentCompensation, instead of the original BAS_BE_CommercialCurtailmentCompensation. That means that the money that the BRP has saved, can be used to pay to the aggregator for the flexibility service. As in the case of the DSO, the BRP would require applying a certain security margin FHP_B_TargetBenefitMargin if it bets for negotiating flexibility with the aggregator, to mitigate inaccuracies in the flexibility settlement. This gives that the BRP could pay to the aggregator an average flat price for flexibility, FHP_BA_SystemFlexibilityPrice.

Once BAS_BE_CommercialCurtailmentCompensation has been calculated, we also calculate the fee that the DER Producer would have to pay to the BRP for the representation service so that it the money that the BRP gets is around a 10% higher than the money that it must pay to the Der Producer to compensate for commercial curtailment. This fee is identical in both scenarios so it does not influence in the cash flow calculation.

Name	Units	Wind
EB_MaxPower	kW	10958000
EB_MaxPower_2018	kW	7400000
UP_YearlyMaxPowerServiceFee	€/kW	1,2
UP_YearlyServiceFee	€	13.149.600
BAS_EB_RepresentationFee	€	13.149.600
BAS_BE_CommercialCurtailmentCompensation	€	11.033.367

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Table 35: UP_YearlyMaxPowerServiceFee

In summary, the money that the BRP has to pay to the aggregator to avoid commercial curtailment, FHP_BA_SystemFlexibilityPayment, added to the final compensation to the DER Producer, FHP_BE_CommercialCurtailmentCompensation, is lower than the initial compensation to the DER Producer, BAS_BE_CommercialCurtailmentCompensation. This positive diference, CF_BRP_UC2, lets the BRP have an economical gain by negotiating flexibility with the aggregator in UC2.

FHP_BA_SystemFlexibilityPrice	c€/kWh	3,14
BAS_BE_CommercialCurtailmentCompensation	€	11.033.367
FHP_BE_CommercialCurtailmentCompensation	€	2.610.012
FHP_BA_SystemFlexibilityPayment	€	7.581.020
CF_BRP_UC2	€	842.336

Figure 79: Cash flow of the BRP in UC2

6.3.4.1.5.2 BalancingServices

This is about the real-time phase flexibility (BRP) payment from the BRP to the aggregator in UC3. It is the BRP the one that determines on its own the price that it pays for flexibility, depending on the capacities (requested price vs flexibility) previously communicated by the aggregator:

$$Payment\ for\ balancing\ service_y = \sum_{h=1}^{8760} Balancing\ service\ price_h * Operation\ phase\ flexibility_h$$

The payment is both associated to consumption increase and to consumption decrease events:

$$BA\_BalancingServicePayment_y = \sum_{q=1}^{4*8760} BA\_BalancingConsumptionIncreasePayment_q + BA\_BalancingConsumptionDecreasePayment_q$$

To increase consumption a certain price is applied to the increased consumption:

$$BA\_BalancingConsumptionIncreasePayment_q = \sum_{q=1}^{4*8760} (BA\_BalancingConsumptionIncreasePrice_q * BA\_BalancingConsumptionIncreaseEnergy_q)$$

Analogously, to decrease consumption a certain price is applicated to the decreased consumption:

$$BA\_BalancingConsumptionDecreasePayment_q = \sum_{q=1}^{4*8760} (BA\_BalancingConsumptionDecreasePrice_q * BA\_BalancingConsumptionDecreaseEnergy_q)$$

The calculation of both the decreased consumption and increased consumption is aggregated considering all the Heat Providers which respond to the aggregator.

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$$BA\_BalancingConsumptionDecreaseEnergy_q = \sum_{hp=1}^{HPs} PR\_BalancingConsumptionDecreaseEnergy_q$$

$$BA\_BalancingConsumptionIncreaseEnergy_q = \sum_{hp=1}^{HPs} PR\_BalancingConsumptionIncreaseEnergy_q$$

We assume that $PR\_BalancingConsumptionIncreaseEnergy_q$ as in UC1 and UC2, can be as much as the stored thermal inertia capacity, but just if the BRP was interested in paying for the consumption increase, if $BA\_BalancingConsumptionIncreasePrice > 0$

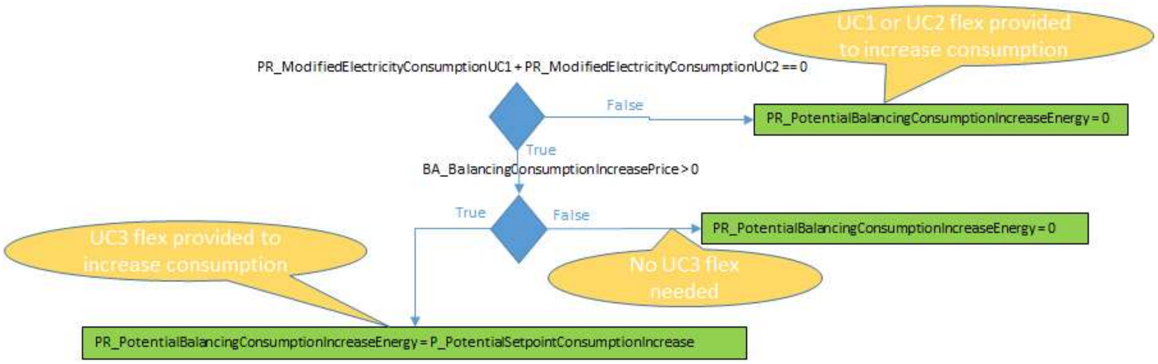

Figure 80: PR_PotentialBalancingConsumptionIncreaseEnergy

And analogously for consumption decrease, if $BA\_BalancingConsumptionDecreasePrice > 0$:

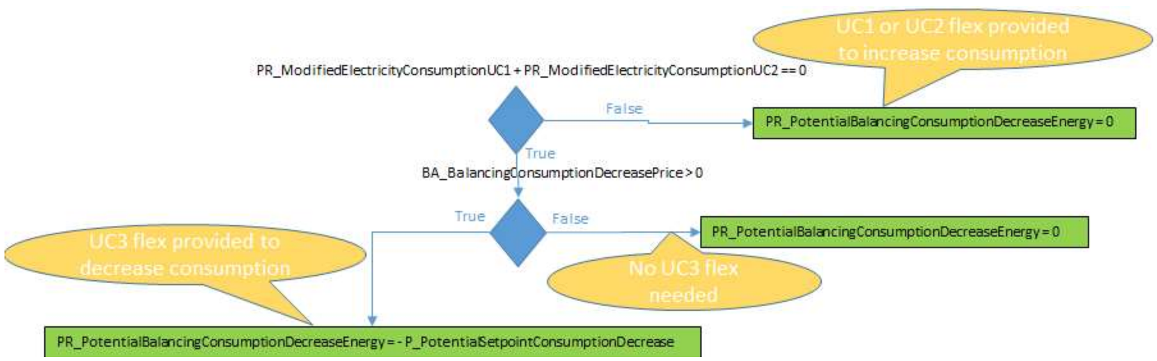

Figure 81: PR_PotentialBalancingConsumptionDecreaseEnergy

BA_BalancingConsumptionDecreasePrice is applied for downwards consumption flexibility in those PTUs in which the BRP wants to act on its position (0 otherwise). Analog reasoning applies to *BA_BalancingConsumptionIncreasePrice.*

The potential setpoint for consumption decrease, based on the state of the thermal inertia and the limitation that the electrical consumption of the Heat Provider cannot be negative (the baseline minus the setpoint for consumption decrease in UC3) is calculated this way:

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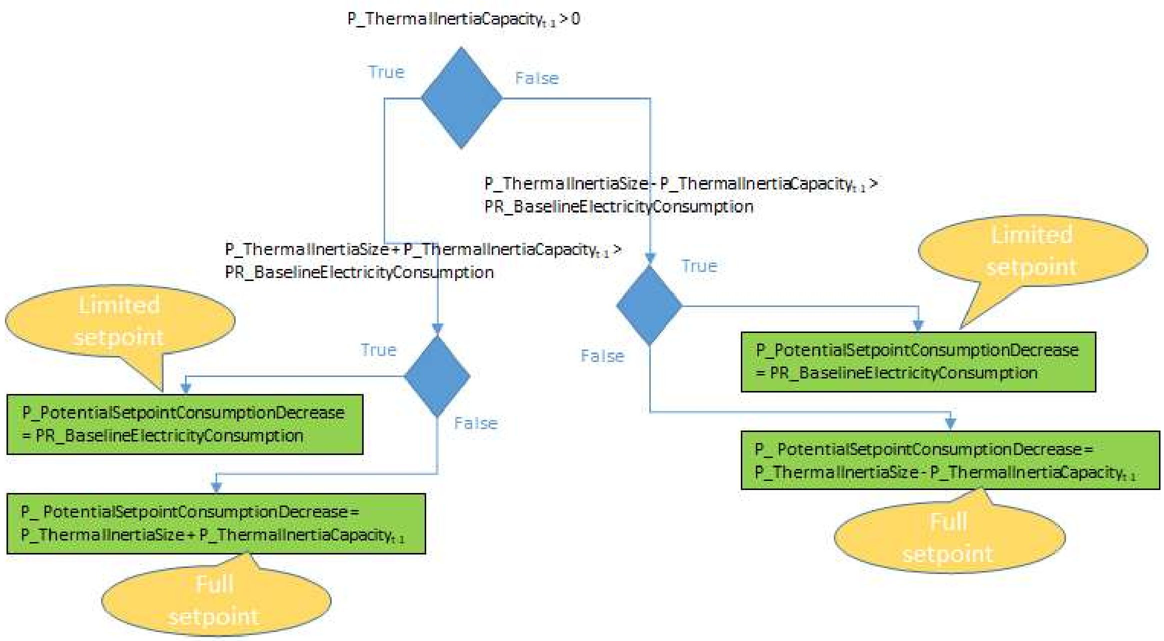

Figure 82: P_PotentialSetpointConsumptionDecrease

The affection of UC3 is decided depending both on the imbalance position and the imbalance prices.

For instance, if the price paid by the BRP to the aggregator to decrease consumption is positive, BA_BalancingConsumptionDecreasePrice, it means that either:

- ✓ The BRP is in a production shortfall situation, and wants to decrease the consumption to reduce its imbalance position (in case that the price that it must pay to the TSO is above a certain threshold representing the average Price that it must pay to aggregators for decreasing consumption)
- ✓ The BRP is in a production surplus situation, and wants to decrease the consumption to increase its imbalance position, because imbalance prices are negative

The assessment of which of these two situations is applicable is done through these variables:

$$BA\_BalancingConsumptionDecreasePrice = MAX(BA\_BalancingConsumptionDecreasePriceDecreaseImbalance; BA\_BalancingConsumptionDecreasePriceIncreaseImbalance)$$

In the following two situations the AGR will decrease its consumption:

- *Reduce shortfall imbalance BRP position on TSO shortfall conditions:* BT_ShortfallImbalancePrice is the price that the BRP must pay to the TSO in case of portfolio production defect, in which case the TSO must activate regulation up (as the TSO is a non-profit party that just forwards regulation cost to those who caused the imbalance). If the BRP will have to pay a penalty if it is in shortfall (real consumption higher than baseline) then it can pay to the aggregators to reduce its imbalance position

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If $BT\_ShortfallImbalancePrice >$ $BA\_BalancingConsumptionDecreaseThresholdPrice$ then

If $BT\_ShortfallImbalanceInitialEnergy > 0$ then

$$BA\_BalancingConsumptionDecreasePriceDecreaseImbalance = BA\_BalancingConsumptionDecreaseThresholdPrice$$

Else $BA\_BalancingConsumptionDecreasePriceDecreaseImbalance$ = 0

Else $BA\_BalancingConsumptionDecreasePriceDecreaseImbalance$ = 0

- *Increase surplus imbalance BRP position on TSO shortfall conditions:* On the contrary, BT_SurpluslImbalancePrice is the price paid by the TSO for the regulation down. In case that this price is negative and higher in absolute value than the price that the BRP would pay so that aggregators decrease consumption, the BRP would be interested in increasing its imbalance position, because he gets a benefit for increasing its imbalance. If the BRP will have to pay a penalty if it is in shortfall (real consumption higher than baseline) then it can pay to the aggregators to increase its imbalance position.

If $BT\_SurplusImbalancePrice < -BA\_BalancingConsumptionDecreaseThresholdPrice$ then

If $BT\_SurplusImbalanceInitialEnergy > 0$ then

$$BA\_BalancingConsumptionDecreasePriceIncreaseImbalance = BA\_BalancingConsumptionDecreaseThresholdPrice$$

Else $BA\_BalancingConsumptionDecreasePriceIncreaseImbalance$ = 0

Else $BA\_BalancingConsumptionDecreasePriceIncreaseImbalance$ = 0

In the following two situations the AGR will increase its consumption:

- *Reduce surplus imbalance BRP position on TSO surplus conditions:* If the BRP will have to pay a penalty if it is in surplus (real consumption lower than baseline), then it can pay to the aggregators to reduce its imbalance position
- *Increase shortfall imbalance BRP position on TSO surplus conditions*: If the BRP will have to pay a penalty if it is in surplus (real consumption lower than baseline), then it can pay to the aggregators to increase its imbalance position

Based on these assumptions, analogue formulation to that in the consumption decrease explanation has been implemented for the case of consumption increase.

The energy that the BRP would use to make the flexibility request to the aggregator, is calculated based on the initial imbalance of the BRP:

If BT_ImbalanceInitialEnergy > 0

$$BT\_SurplusImbalanceInitialEnergy = BT\_ImbalanceInitialEnergy$$

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$$BT\_ShortfallImbalanceInitialEnergy = 0$$

Else

$$BT\_SurplusImbalanceInitialEnergy = 0$$

$$BT\_ShortfallImbalanceInitialEnergy = -BT\_ImbalanceInitialEnergy$$

And the imbalance of the BRP is calculated using the national production and consumption real neasurements compared to the prognosis:

$$BT\_ImbalanceInitialEnergy = MB\_ProducersElectricityReal - MBProducersElectricityBaseline - BM\_ConsumersElectricityReal + BM\_ConsumersElectricityBaseline$$

Now we calculate BA_PotentialBalancingConsumptionDecreaseEnergy the flexibility that the Heat Providers in the portfolio of the aggregator provide for consumption decrease. To calculate this, first we calculate the max flex that the whole portfolio of the aggregator can provide, BA_ PotentialBalancingConsumptionDecreaseEnergy.

$$BA\_PotentialBalancingConsumptionDecreaseEnergy = \sum_{q=1}^{4} PR\_PotentialBalancingConsumptionDecreaseEnergy * Number\ HeatProvidersTypeQ$$

And the same for consumption increase:

$$BA\_PotentialBalancingConsumptionIncreaseEnergy = \sum_{q=1}^{4} PR\_PotentialBalancingConsumptionIncreaseEnergy * Number\ HeatProvidersTypeQ$$

Where PR_ PotentialBalancingConsumptionIncreaseEnergy and PR_ PotentialBalancingConsumptionDecreaseEnergy are the maximum flexibility that could provide each Heat Provider, depending on the current capacity of its thermal inertia and limitated by its contracted power. Consider that due to the prioritization of use cases in this CBA analysis, flex just can be provided in UC3 if it has not been provided neither in UC1 nor in UC2.

Then, considering both situations in which the BRP would pay for consumption decrease, we calculate the amount of flexibility requested to the aggregator. In case that we act to decrease the imbalance position of the BRP, the request contains the imbalance value. In case that we want to increase the imbalance position of the BRP because of negative imbalance prices, then we set the requested value to the potential flexibility of the aggregator.

If BA_BalancingConsumptionDecreasePriceDecreaseImbalance > 0

BA_BalancingConsumptionDecreaseRequest = BT_ShortfallImbalanceInitialEnergy

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If BA_BalancingConsumptionDecreasePriceIncreaseImbalance > 0

BA_BalancingConsumptionDecreaseRequest = BA_PotentialBalancingConsumptionDecreaseEnergy

And the same for consumption increase:

If BA_BalancingConsumptionIncreasePriceDecreaseImbalance > 0

BA_BalancingConsumptionIncreaseRequest = T_SurplusImbalanceInitialEnergy

If BA_BalancingConsumptionIncreasePriceIncreaseImbalance > 0

BA_BalancingConsumptionIncreaseRequest = BA_PotentialBalancingConsumptionIncreaseEnergy

Now we calculate the flexibility that will be provided as the minimum value between that requested by the BRP and the one offered by the aggregator.

BA_BalancingConsumptionIncreaseEnergy=min(BA_PotentialBalancingConsumptionIncreaseEnergy, BA_BalancingConsumptionIncreaseRequest)

BA_BalancingConsumptionDecreaseEnergy=min(BA_PotentialBalancingConsumptionDecreaseEnergy , BA_BalancingConsumptionDecreaseRequest)

Finally, the limitation is propagated backwards to calculate the real flexibility provided by each Heat Provider:

$$PR\_BalancingConsumptionDecreaseEnergy = PR\_PotentialBalancingConsumptionDecreaseEnergy * BA\_BalancingConsumptionDecreaseEnergy / BA\_PotentialBalancingConsumptionDecreaseEnergy$$

$$PR\_BalancingConsumptionIncreaseEnergy = PR\_PotentialBalancingConsumptionIncreaseEnergy * BA\_BalancingConsumptionIncreaseEnergy / BA\_PotentialBalancingConsumptionIncreaseEnergy$$

From the data, we observe that predominantly the BRP is in a surplus situation, because BT_ImbalanceInitialEnergy is positive. This means that in most of the cases in UC3 it will be prone to pay to the aggregators to increase their consumption to decrease its imbalance payment.

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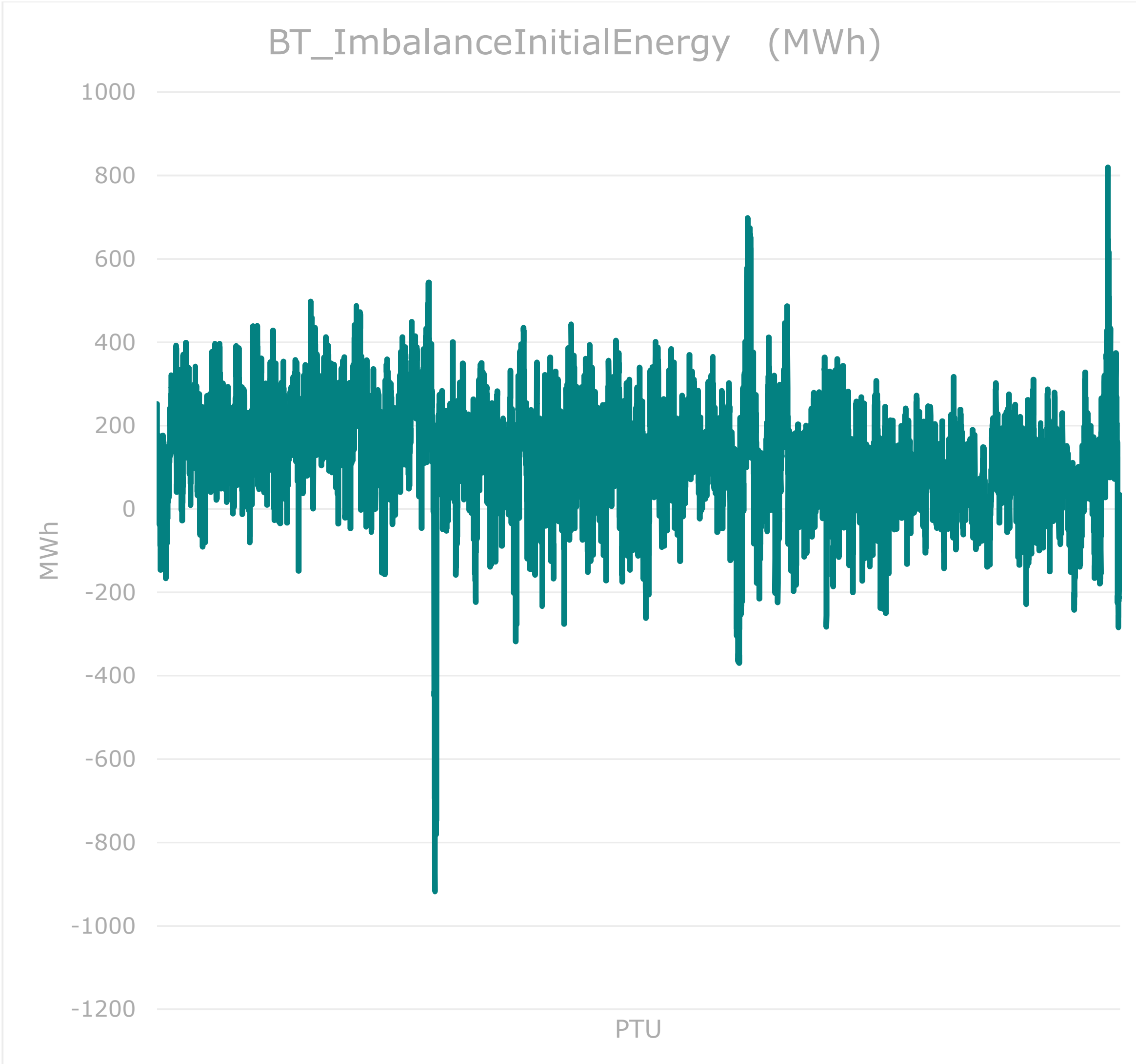

Figure 83: Initial imbalance position of the BRP

In order to assess the imbalance prices, we use as best approach the regulation prices published by NordPool:

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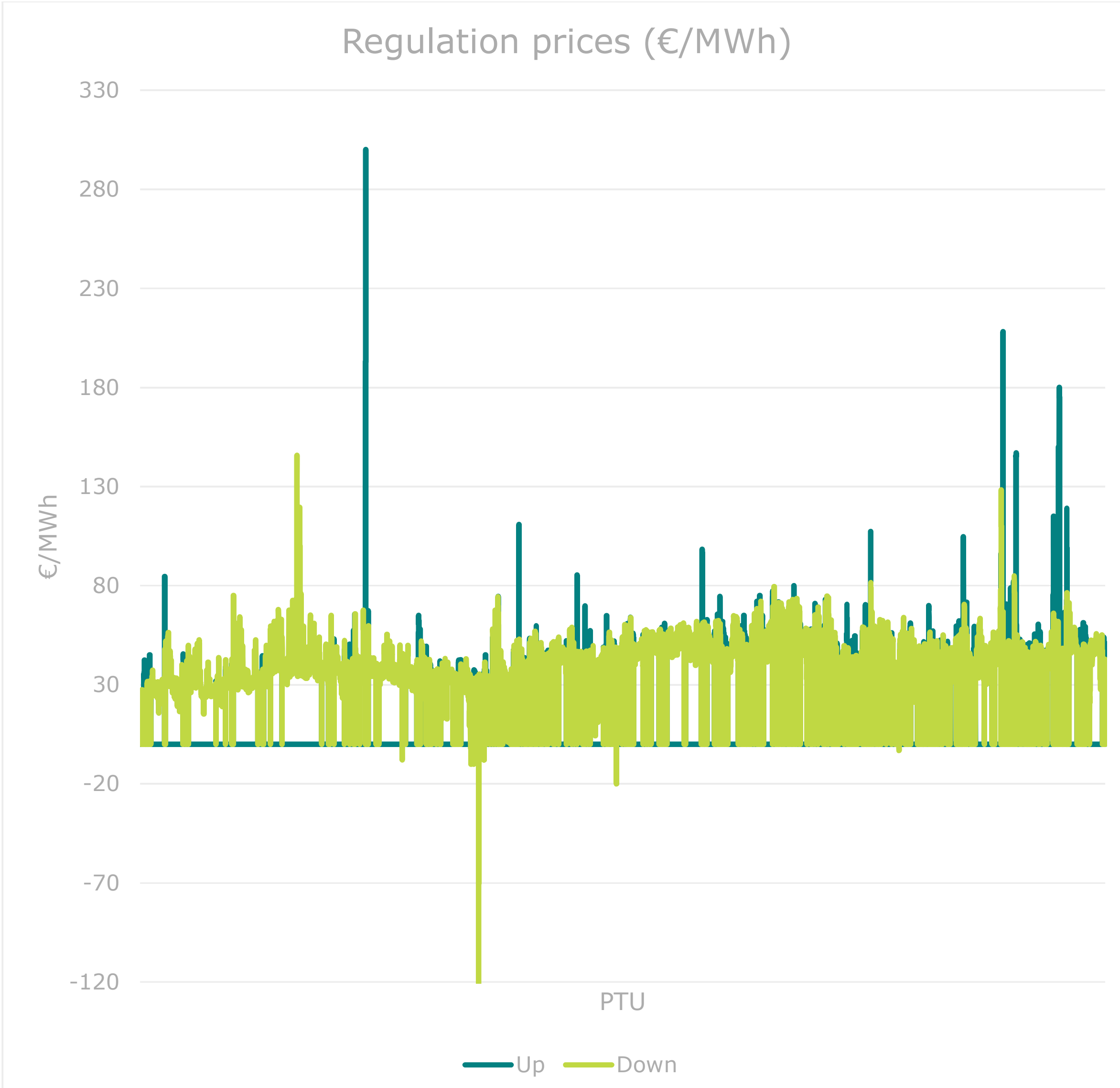

Figure 84: Imbalance prices paid by the BRP to the TSO

We have screened the prices with BT_ImbalanceInitialEnergy, so that to get a meaningful BT_ShortfallImbalancePrice (up) and BT_SurplusImbalancePrice (down). As we have seen that the BRP is mainly in surplus, the BT_SurplusImbalancePrice will be more frequently applied.

BT_ShortfallImbalancePrice has been taken from the regulating prices up of the NordPool (as the TSO is a non-profit party that just forwards regulation cost to those who caused the imbalance). On the contrary, BT_SurplusImbalancePrice is the price paid by the TSO for the regulation down. These prices have been filtered with the real regulation volumes, so that in those periods where the volume of regulation up has been zero BT_ShortfallImbalancePrice is set to zero, and when the volume of regulation down has been zero BT_SurplusImbalancePrice is set to zero. This is needed because the prices data downloaded from NordPool are not meaningful for itself, i.e. the existence of a price is not related to the existence of a need by the TSO.

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With these prices and considering the price threshold defined to decide whether for the BRP it is profitable to contract flexibility to the aggregator or not, we get the following balancing consumption prices. A positive price means that in that time period the BRP is willing to pay to the aggregator for flexibility in UC3.

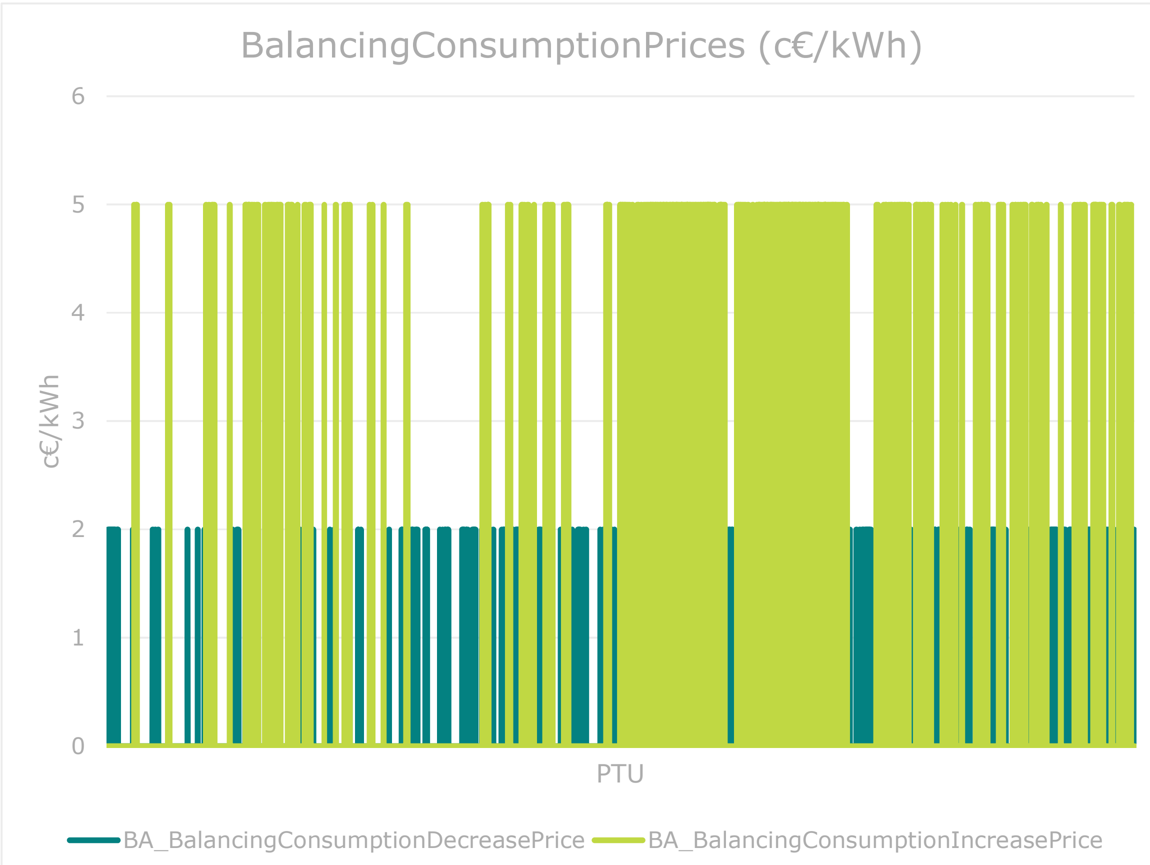

Figure 85: Prices paid by the BRP to the aggregator for the balancing service

The numbers for the consumption increase are these:

BA_BalancingConsumptionIncreaseRequest	kWh	878.055.000
BA_PotentialBalancingConsumptionIncreaseEnergy	kWh	9.812.882.220
BA_BalancingConsumptionIncreaseEnergy	kWh	575.144.513

Table 36: Consumption increase

The situation about consumption increase is even more radical, in the sense that there is not even a single time slot in which the BRP can request flexibility to increase its imbalance position due to a negative BT_ShortfallImbalancePrice.

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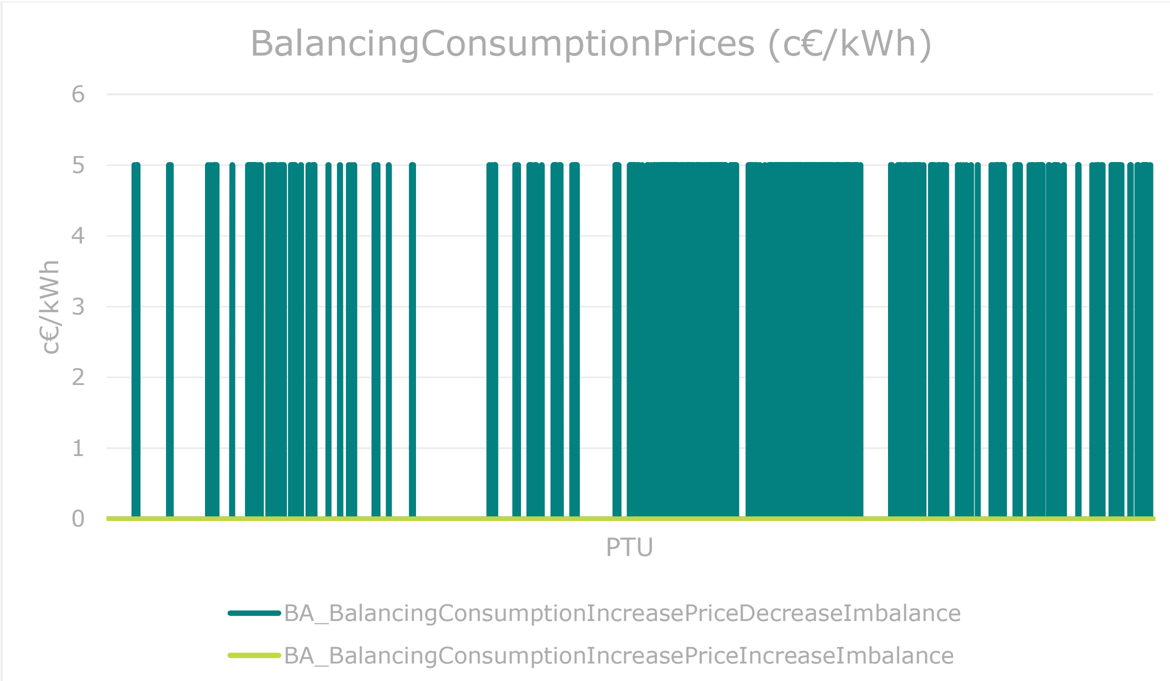

Figure 86: Balancing consumption prices for consumption increase

The profiles that we obtain for the flexibility request, the potential flexibility and the flexibility provided are the following:

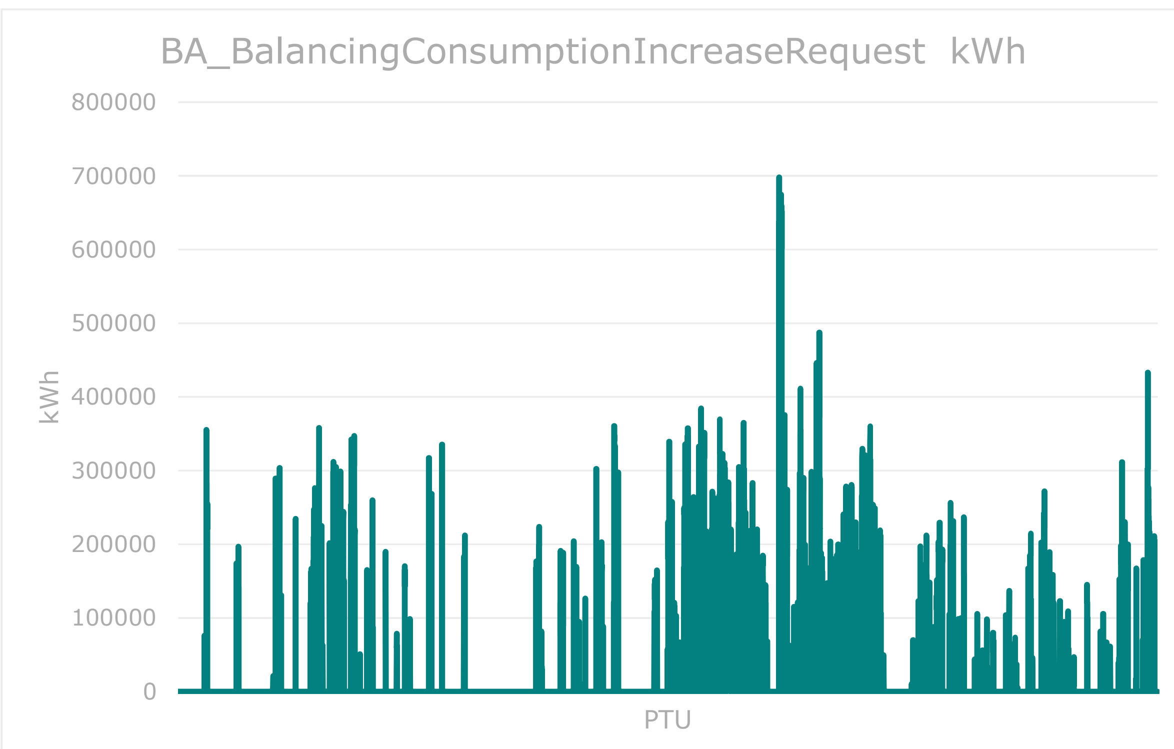

Figure 87: Flexibility request

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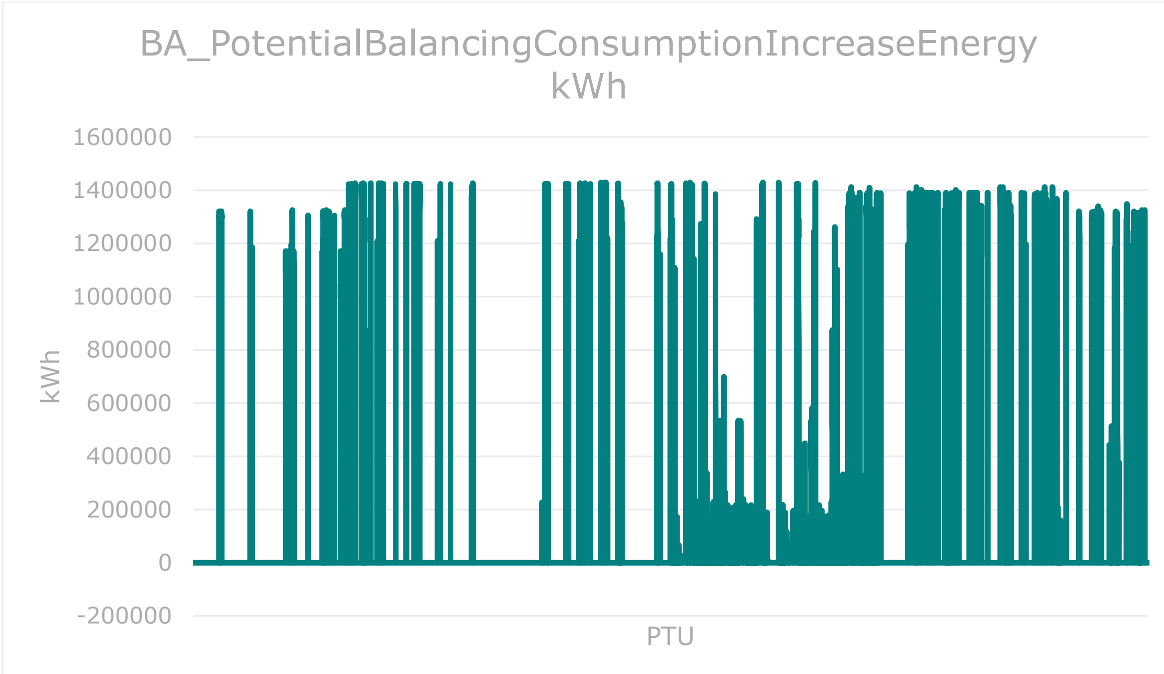

Figure 88: Potential flexibility

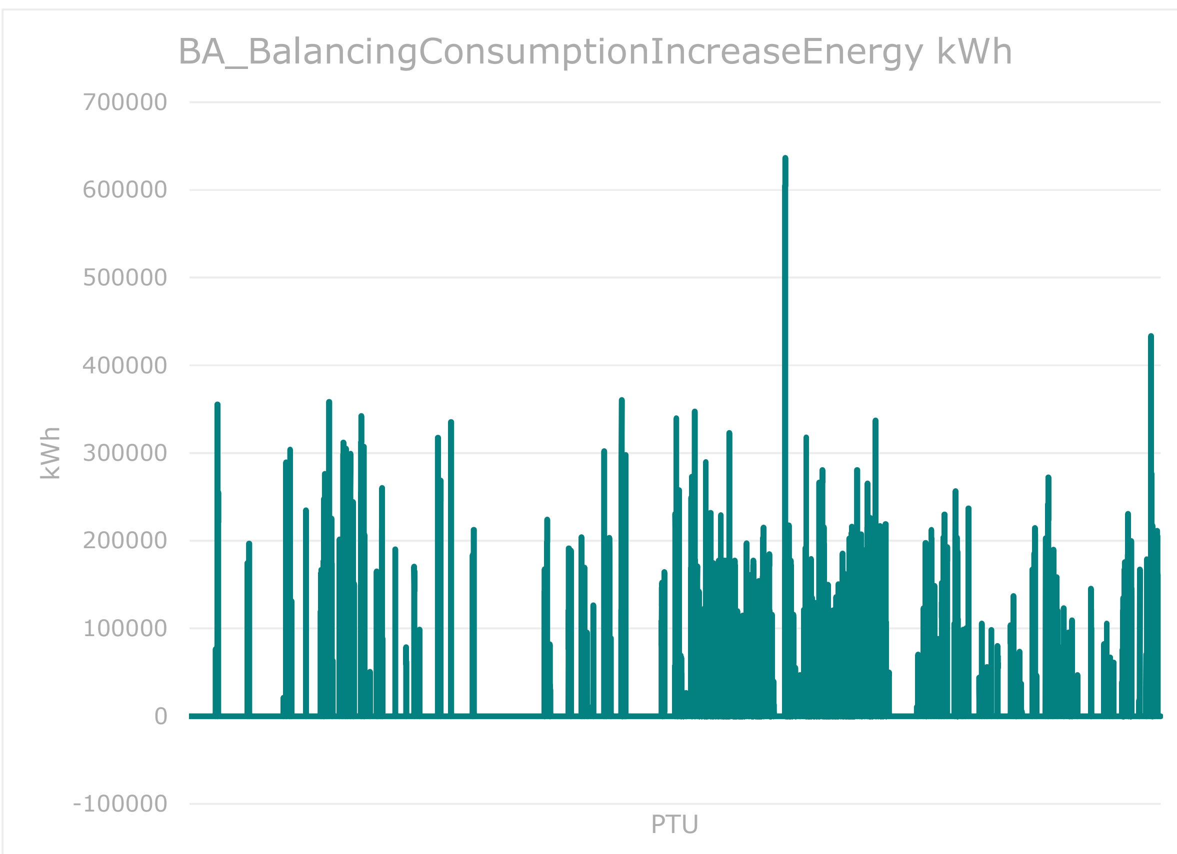

Figure 89: Provided flexibility

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Here they are the three above magnitudes in the same char, and zooming in the PTUs from 2000 to 21000:

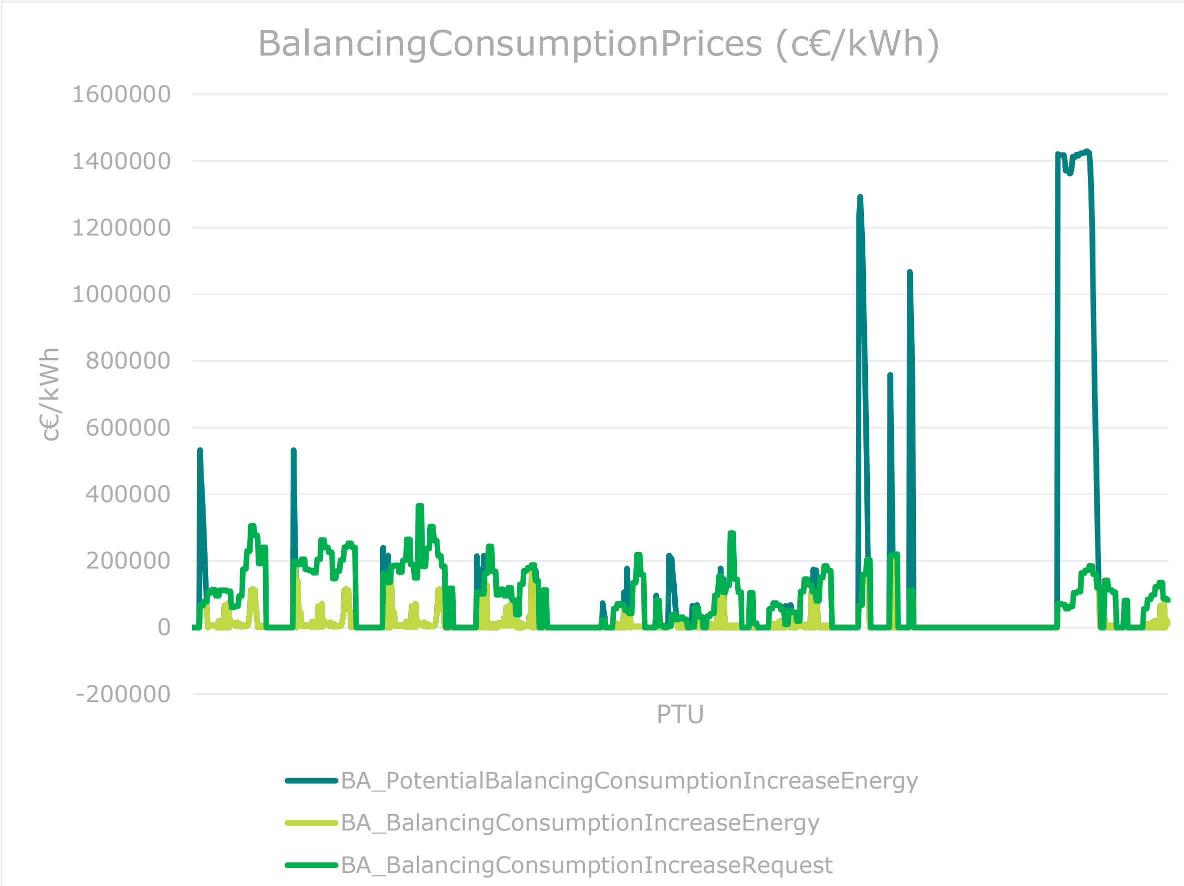

Figure 90: Requested vs potential vs provided flexibility. PTUs from 20000 to 30000

Analogously, the numbers for the consumption decrease are these:

BA_BalancingConsumptionDecreaseRequest	kWh	364.204.806
BA_PotentialBalancingConsumptionDecreaseEnergy	kWh	1.242.479.038
BA_BalancingConsumptionDecreaseEnergy	kWh	247.050.833

Table 37: Consumption decrease

Based on the assumptions considered to calculate in which situations the BRP would request flexibility to decrease the consumption of the Heat Providers, we check that the absolute majority is due to decrease the imbalance situation of the BRP. That is because situations where the BT_SurplusImbalancePrice are negative are very rare.

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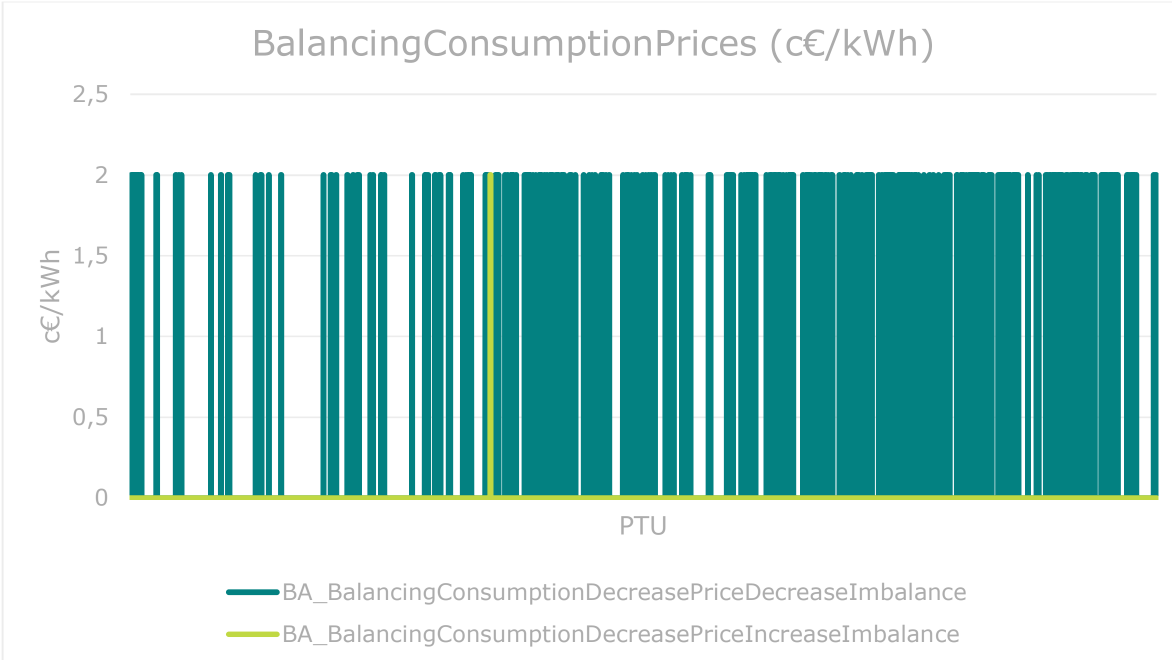

Figure 91: Balancing consumption prices for consumption decrease

In this case, the profiles that we obtain for the flexibility request, the potential flexibility and the flexibility provided are the following:

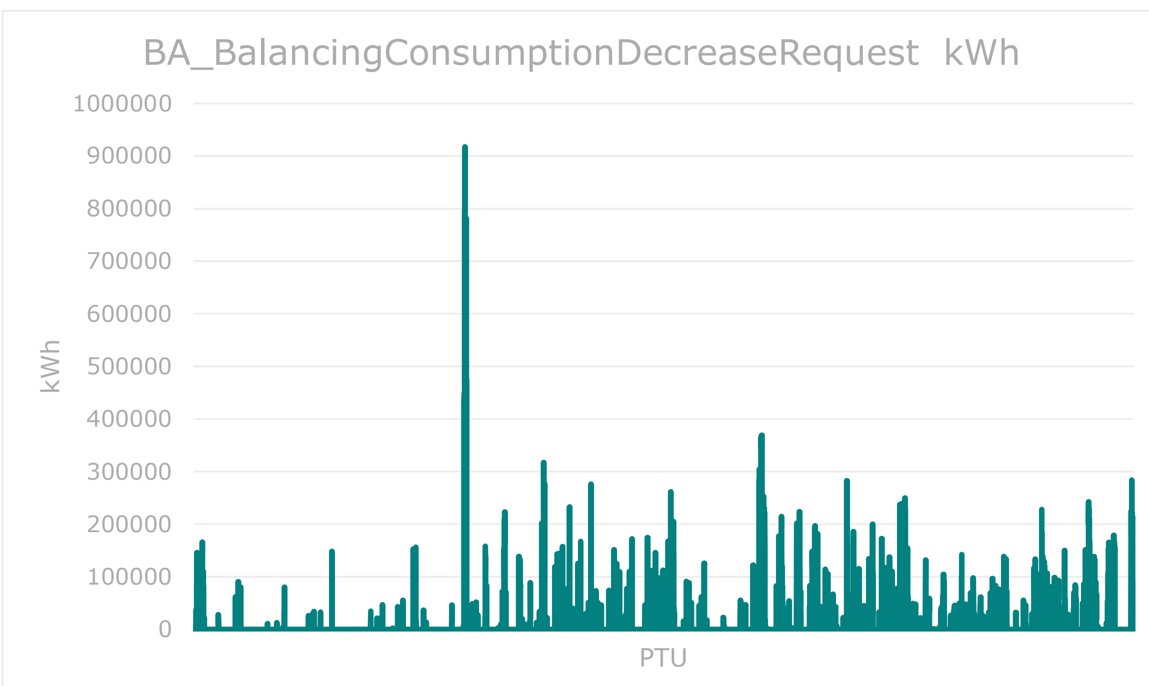

Figure 92: Flexibility request

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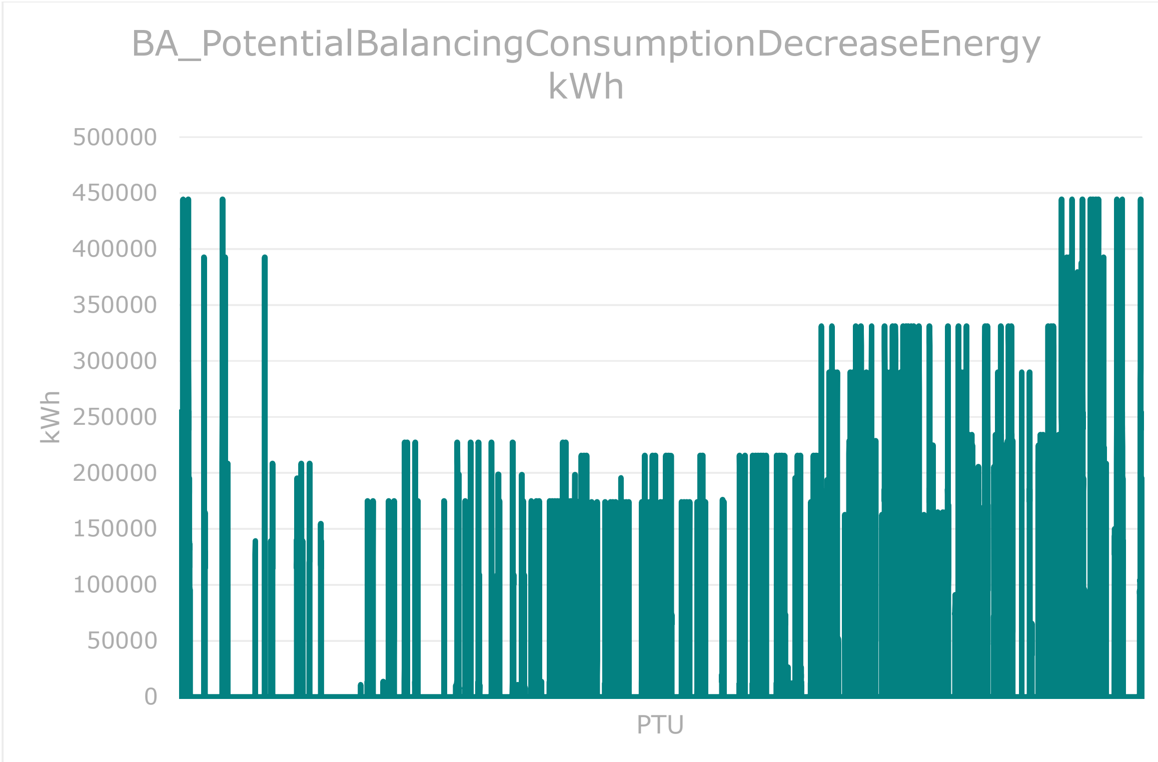

Figure 93: Potential flexibility

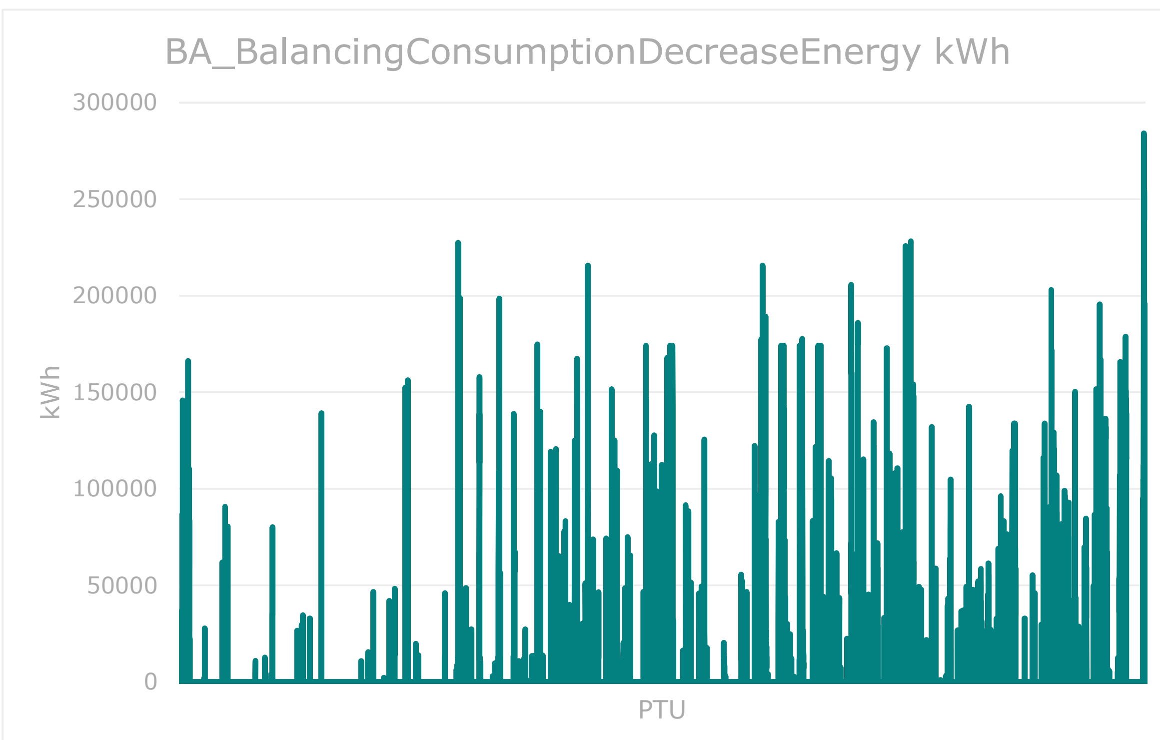

Figure 94: Provided flexibility

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And the three above magnitudes in the same chart, and zooming in the PTUs from 0 to 600:

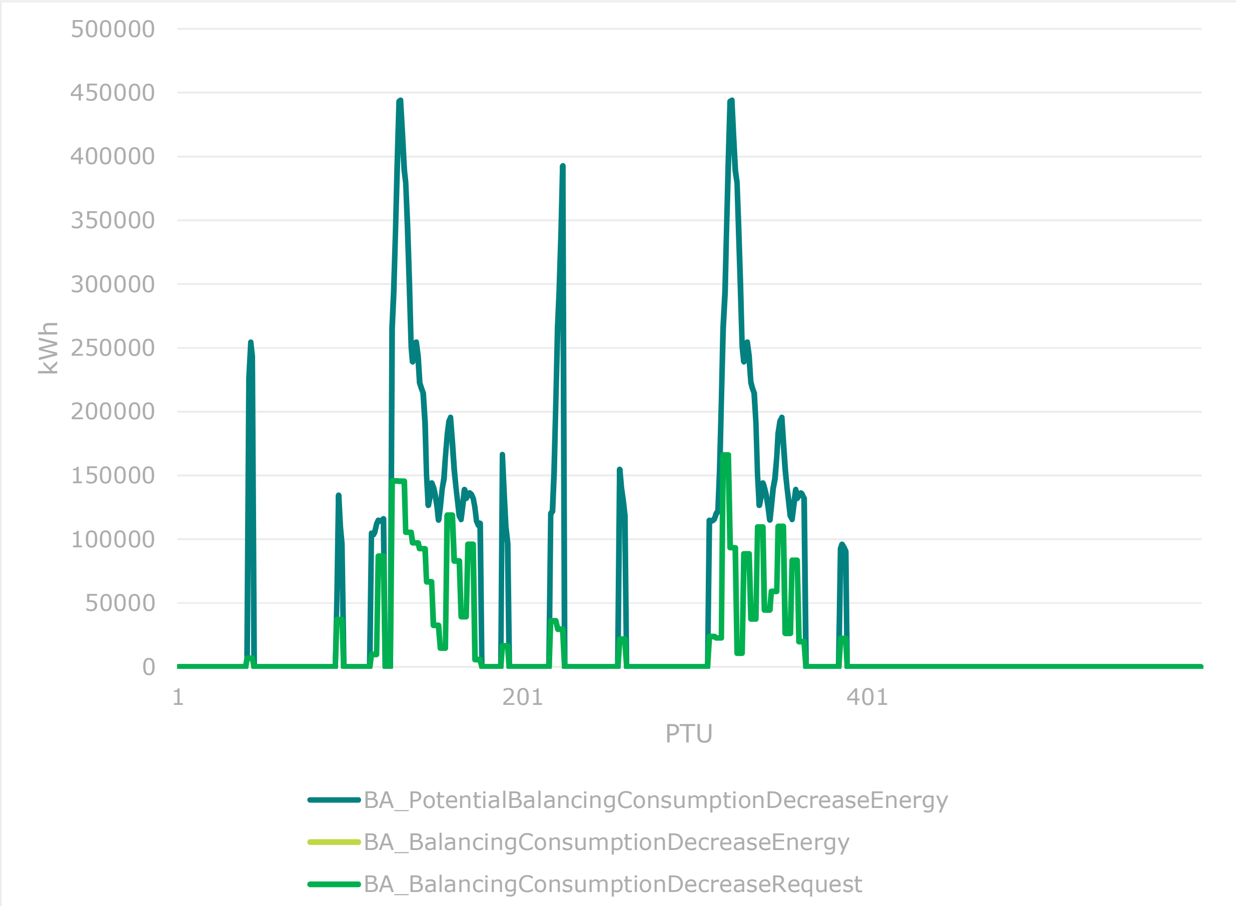

Figure 95: Requested vs potential vs provided flexibility. PTUs from 0 to 600

With the thresholds defined, we check that the BRP requests a much larger consumption increase to the aggregator, compared to the consumption decrease.

Considering both consumption increase and decrease profiles, because of the FHP flexibility provided, the BRP is affected on the payments it executes to the DSO in this way:

BAS_BT_ImbalancePayment	€	216.819.998
FHP_BT_ImbalancePayment	€	170.099.624
FHP_BA_BalancingServicePayment	€	33.698.242

Table 38: BRP imbalance payments in both BAS and FHP scenarios

As a conclusion, the money that the BRP has to pay to the TSO because of its imbalance in the BAS scenario, BAS_BT_ImbalancePayment, is bigger than what it has to pay in the FHP scenario, FHP_BT_ImbalancePayment, plus the payment for the aggregator, FHP_BA_BalancingServicePayment. This positive diference, CF_BRP_UC3, lets the BRP have an economical gain by negotiating flexibility with the aggregator in UC3, which is even much larger than the benefit for mitigating system level renewable curtailment in UC2.

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BA_BalancingConsumptionDecreaseThresholdPrice	c€/kWh	2
BA_BalancingConsumptionIncreaseThresholdPrice	c€/kWh	5
BAS_BT_ImbalancePayment	€	216.819.998
FHP_BT_ImbalancePayment	€	170.099.624
FHP_BA_BalancingServicePayment	€	33.698.242
CF_BRP_UC3	€	13.022.132

Figure 96: Cash flow of the BRP in UC3

6.3.4.1.6 Aggregator

This relates to the consumption flexibility, by means which the aggregator pays a relative incentive to the Heat Provider (always positive) or the aggregator pays an absolute incentive to the Heat Provider (it can be either positive or negative). This incentive is added on top of the tariff paid by the Heat Provider to the retailer.

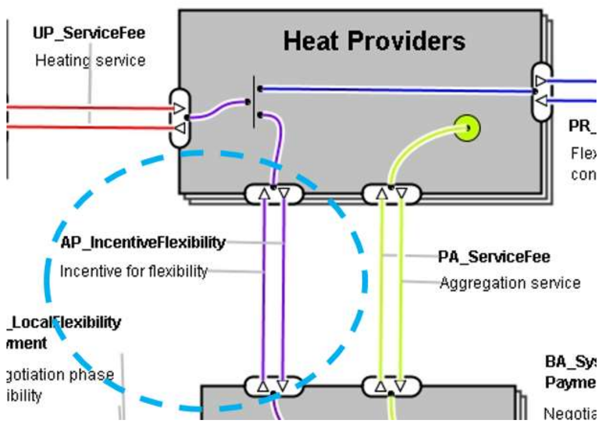

Figure 97: FHP_AP_IncentiveFlexibility

$$FHP\_AP\_IncentiveFlexibility_y = \sum_{q=1}^{4*8760} AP\_IncentiveFlexibilityPayment_q$$

Being:

$$AP\_IncentiveFlexibilityPayment_q = AP\_Incentive_q * PR\_RealElectricityConsumption_q$$

For simplicity, we assume that there is an Aggregator for all Heat Providers. The incomes that the aggregator gets from the DSO and BRP because of the flexibility sale must be used to incentivize the response of the Heat Providers.

FHP_BA_SystemFlexibilityPayment	€	7.581.020
FHP_DA_LocalFlexibilityPayment	€	9.553.645
FHP_BA_BalancingServicePayment	€	33.698.242
A_TotalFlexibilityIncomes	€	50.832.907

Figure 98: Aggregator flexibility incomes

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$$A\_TotalFlexibilityIncomes\ = FHP\_BA\_SystemFlexibilityPayment + FHP\_DA\_LocalFlexibilityPayment\ +\ FHP\_BA\_BalancingServicePayment$$

Being the payment from UC3, BalancingServices, due to both a consumption increase and decrease:

$$\begin{aligned} FHP\_BA\_BalancingServicePayment & \\ &= FHP\_BA\_BalancingServiceConsumptionDecreasePayment \\ &+ FHP\_BA\_BalancingServiceConsumptionIncreasePayment = \\ &= (BA\_BalancingConsumptionIncreaseThresholdPrice \\ &+ BA\_BalancingConsumptionIncreaseEnergy) \\ &+ (BA\_BalancingConsumptionIncreaseThresholdPrice \\ &+ BA\_BalancingConsumptionIncreaseEnergy) \end{aligned}$$

FHP_BA_BalancingServiceConsumptionDecreasePayment	€	4.941.017
FHP_BA_BalancingServiceConsumptionIncreasePayment	€	28.757.226

Figure 99: Balancing service payments

Then, if we separate the payments from the DSO/BRP about consumption decrease from those about consumption increase:

$$\begin{aligned} A\_ConsumptionIncreaseFlexibilityIncomes & \\ &= FHP\_BA\_BalancingServiceConsumptionIncreasePayment \\ &+ FHP\_BA\_SystemFlexibilityPayment + FHP\_DA\_LocalFlexibilityPayment \end{aligned}$$

$$\begin{aligned} A\_ConsumptionDecreaseFlexibilityIncomes & \\ = FHP\_BA\_BalancingServiceConsumptionDecreasePayment \end{aligned}$$

A_ConsumptionDecreaseFlexibilityIncomes	€	4.941.017
A_ConsumptionIncreaseFlexibilityIncomes	€	45.891.891

Figure 100: Payments for consumption decrease/increase

Related to these payments, we calculate the energy terms:

$$A\_ConsumptionDecreaseEnergy = BA\_BalancingConsumptionDecreaseEnergy$$

$$\begin{aligned} A\_ConsumptionIncreaseEnergy & \\ = BA\_SystemFlexibilityEnergy + DA\_LocalFlexibilityEnergy & \\ + BA\_BalancingConsumptionIncreaseEnergy \end{aligned}$$

A_ConsumptionDecreaseEnergy	kWh	247.050.833
A_ConsumptionIncreaseEnergy	kWh	1.078.118.270

Figure 101: Energy flexibility decrease/increase

In the design of the FHP use cases we left the door open to two different mechanisms to promote consumption increase/decrease on the Heat Provider side: absolute or relative incentives.

- ✓ Absolute incentives are applied to the whole consumption of the Heat Provider. When a consumption decrease is desired the aggregator imposes a negative incentive that is added

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on top of the energy price paid by the Heat Provider to the retailer and increase the energy price paid by the Heat Provider. This way, the Heat Provider must pay to the aggregator for each kWh that it consumes, and consequently the Heat Provider decreases its consumption to limit the energy expenditure. On the contrary, to stimulate consumption increase, the aggregator pays a positive incentive to the Heat Provider. The application of these kind of incentives requires a high commitment on the Heat Provider side, because it must accept to pay to the aggregator on consumption decrease events.

- ✓ Using relative incentives, the Heat Provider always receives a positive incentive which is related to the flexibility provided, compared to its baseline, both for consumption increase and decrease. This is the way incentives work between the aggregator and the DSO/BRP, as it is originally implemented in flexibility frameworks as USEF.

We selection of whether to use absolute or relative incentives must be based on the expected roll up of Heat Providers because of the attractiveness of the type of incentive, Maybe relative incentives, where the Heat Providers always get money for flexibility, or more trustful for Heat Providers who will be feared of an aggregator which majorly imposes negative incentives and increases the effective price of energy. It is true that the ratio between positive and negative absolute incentive events should be limited by contract, in order to avoid this, roll up barrier, but it would be difficult to convince to the Heat Providers of the fairness of this approach.

In this cost benefit analysis study, we used relative incentives and now that we know what the flexibility energy and the related payment has been, both for consumption decrease and increase, that the aggregator has received. We consider that the aggregator will forward these payments to the Heat Providers as incentives to stimulate their consumption decrease/increase. From the point of view of the Heat Provider, it is pretty the same if the flexibility request comes from an actor or another, or what is the use case in which flexibility is used. Therefore, we calculate the average price that the aggregator is getting from consumption decrease and increase and we forward these average prices to the incentives that the aggregator offers to the Heat Providers. Consequently, the incentives for the Heat Providers are:

$$AP\_ConsumptionIncreaseIncentive = 100 * A\_ConsumptionIncreaseFlexibilityIncomes / A\_ConsumptionIncreaseEnergy$$

$$AP\_ConsumptionDecreaseIncentive = 100 * A\_ConsumptionDecreaseFlexibilityIncomes / A\_ConsumptionDecreaseEnergy$$

AP_ConsumptionDecreaseIncentive	c€/kWh	2,00
AP_ConsumptionIncreaseIncentive	c€/kWh	4,26

Figure 102: Incentives for consumption decrease/increase

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$$
\begin{aligned}
&AP\_IncentiveFlexibility \\
&= ((PR\_ModifiedElectricityConsumptionUC1 \\
&+ PR\_ModifiedElectricityConsumptionUC2 \\
&+ PR\_BalancingConsumptionIncreaseEnergy) \\
&* AP\_ConsumptionIncreaseIncentive/100) \\
&+ (PR\_BalancingConsumptionDecreaseEnergy) \\
&* AP\_ConsumptionDecreaseIncentive/100)
\end{aligned}
$$

FHP_AP_IncentiveFlexibility	€	50.832.907

Figure 103: Overall incentives paid by the aggregator

When the aggregator distributes these incentives to all the Heat Providers, the money that each Heat Provider gets for providing flexibility in a year is:

Name	Units	SFB	MFB	Office	Commercial
Index		1	2	3	4
Number		1.250.000	37.500	25.000	2.500
FHP_AP_IncentiveFlexibility	€	22	405	244	763

Figure 104: Iincentives paid by the aggregator to each Heat Provider

But it is not just that the Heat Provider gets money without any spending, because each Heat Provider pays to the aggregator PA_YearlyServiceFee related to the cost of deploying the FHP technology that enables to the Heat Providers to manage and sell their flexibility. This payment is related to the contracted power of the Heat Provider and is used to amortize the technology deployment done by the aggregator.

Name	Units	SFB	MFB	Office	Commercial
Index		1	2	3	4
Number		1.250.000	37.500	25.000	2.500
Number HeatUsers TypeX		1,00	40,00	1,00	10,00
PR_ContractedPower	kW	6,34	116,21	63,53	196,93
FeeToPowerRatio	€/kW	2,00	2,00	2,00	2,00
PA_YearlyServiceFee	€	13	232	127	394
PA_MaxPower	kW	6,34	116,21	63,53	196,93
FHP_PA_ServiceFee	€	13	232	127	394

Figure 105: PA_YearlyServiceFee

Summing up all the fees paid by the Heat Providers, the aggregator would receive a yearly FHP_PA_ServiceFee.

FHP_PA_ServiceFee	€	28.727.055

Figure 106: FHP_PA_ServiceFee

Once the cost of deploying the FHP technology has been assessed, the value of FeeToPowerRatio should be recalculated, so that the system would be amortised in a reasonable period of time, for instance 5 years.

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With the numbers that we used the yearly benefit for each provider due to the enrolment in the FHP program is:

Name	Units	SFB	MFB	Office	Commercial
BAS_CF_HeatProvider	€	153	2.805	1.766	5.474
FHP_CF_HeatProvider	€	161	2.954	1.775	5.517
CF_HeatProvider	€	8	149	9	44

Figure 107: Cash flow of the Heat Provider

And the cash flow of the aggregator, which is related to the service fee paid by the Heat Providers and which serves to amortize the FHP infrastructure:

BAS_CF_Aggregator	€	0
FHP_CF_Aggregator	€	28.727.055
CF_Aggregator	€	28.727.055

Figure 108: Cash flow of the Aggregator

6.3.4.1.7 Influence of heat pump penetration in curtailment mitigation

Additionally, to this, we have studied the influence of HP_Share, the percentage of the dwellings equipped with heat pumps in the country, in the final curtailment. We have studied different scenarios where the penetration of heat pumps as primary source of buildings ranges from the current value, 20,6% in 2018, to the 100%, assuming that all heat pumps would be enrolled in the FHP programme to provide flexibility.

HP Share	%	20	30	40	50	60	70	80	90	100
InitialGridCurtailmentRatio	%	5,51	5,51	5,51	5,51	5,51	5,51	5,51	5,51	5,51
FinalGridCurtailmentRatio	%	4,98	4,68	4,36	4,08	3,79	3,52	3,28	3,06	3,06
InitialCommercialCurtailmentRatio	%	2,23	2,23	2,23	2,23	2,23	2,23	2,23	2,23	2,23
FinalCommercialCurtailmentRatio	%	1,24	0,96	0,75	0,60	0,49	0,39	0,33	0,29	0,25
InitialTotalCurtailmentRatio	%	7,74	7,74	7,74	7,74	7,74	7,74	7,74	7,74	7,74
FinalTotaCurtailmentRatio	%	6,22	5,64	5,10	4,68	4,28	3,90	3,61	3,35	3,31
CurtailmentReduction	%	19,63	27,12	34,05	39,51	44,76	49,56	53,39	56,69	57,24

Table 39: Final curtailment ratio sensibility to HP_Share

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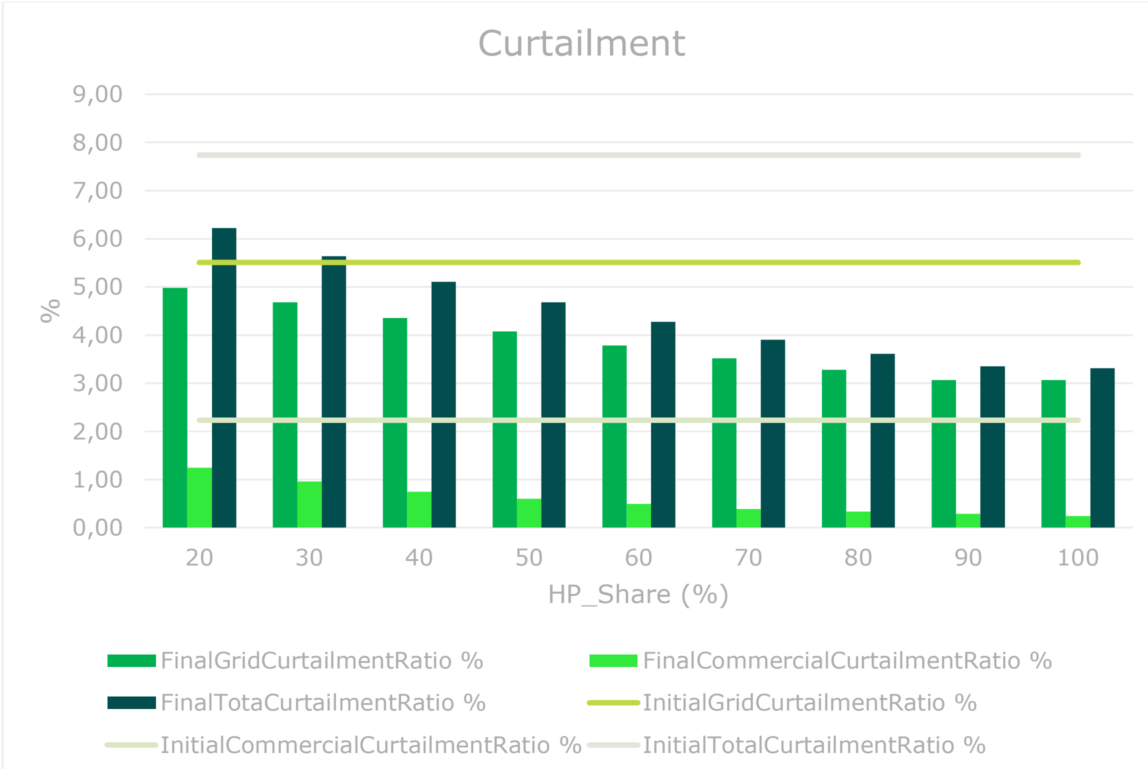
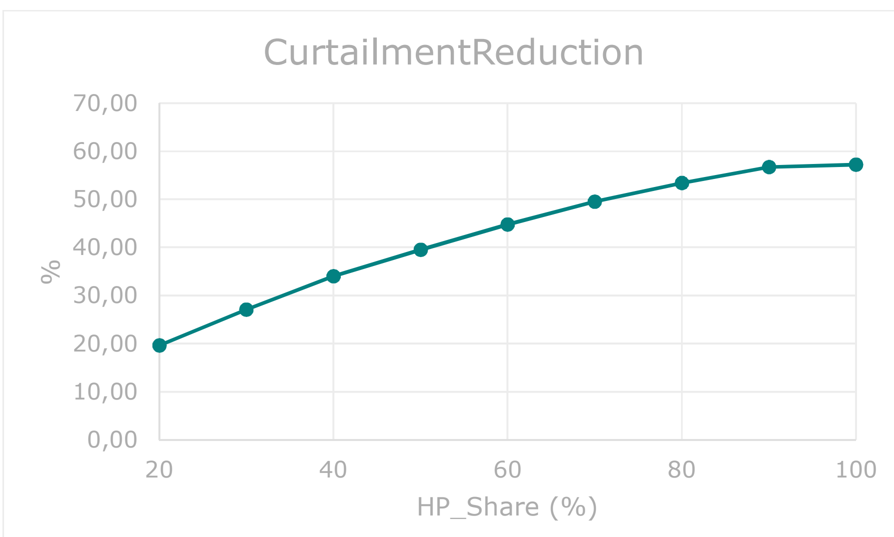


Figure 109: Curtailment vs HP_Share

The higher the penetration is, the lower the final renewable curtailment is, ranging from the 19,63% of potential curtailment reduction with the current heat pump penetration to the 57,24% if heat pumps are fully used.



The shape of the curtailment reduction has a direct relationship with the capabilities of the Heat Providers to provide flexibility, because the response of the Heat Providers upon a concrete flexibility request has a strong dependence on the state of its internal thermal inertia.

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Depending on the potential flexibility available on the Heat Provider side, the need of the aggregator to cover the flexibility requested by the DSO/BRP will be fulfilled or not.

For instance, for UC1, if we represent the evolution through the whole yearly simulation period of the flexibility request, the potential flexibility response and the real flexibility response, for the whole portfolio of the aggregator, we get the following figure.

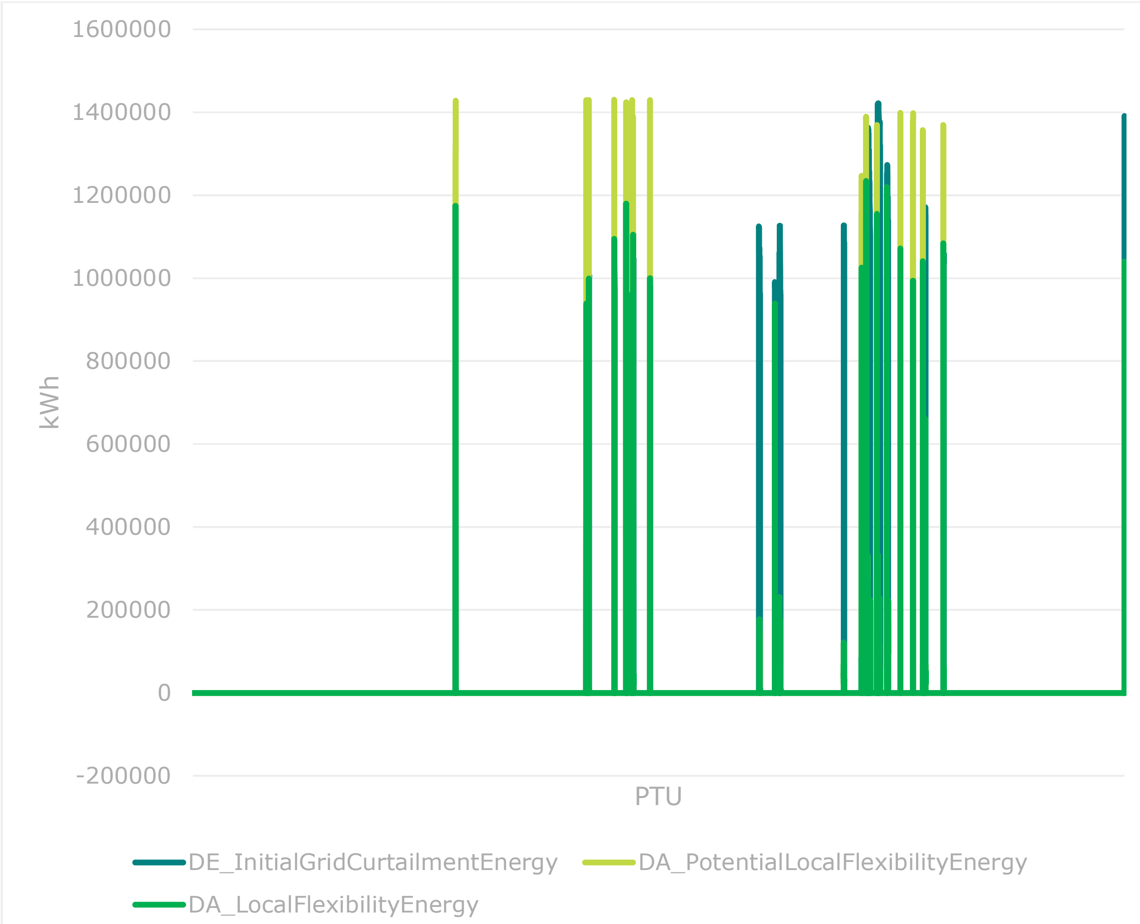

Figure 110: Evolution of local flexibility energy

In that figure we can see some spikes in which potential flex is much larger then flex requested, in opposition to other PTUs in which flex response is much smaller that flex request.

If we make the analysis for a Heat Provider of type 1, a Single-Family Dwelling, and we order the dataset by decreasing values of DE_InitialGridCurtailmentEnergy, and we filter those PTUs with DE_InitialGridCurtailmentEnergy = 0, we obtain the next figure. This figure contains the data of the 739 PTUs in which DE_InitialGridCurtailmentEnergy > 0.

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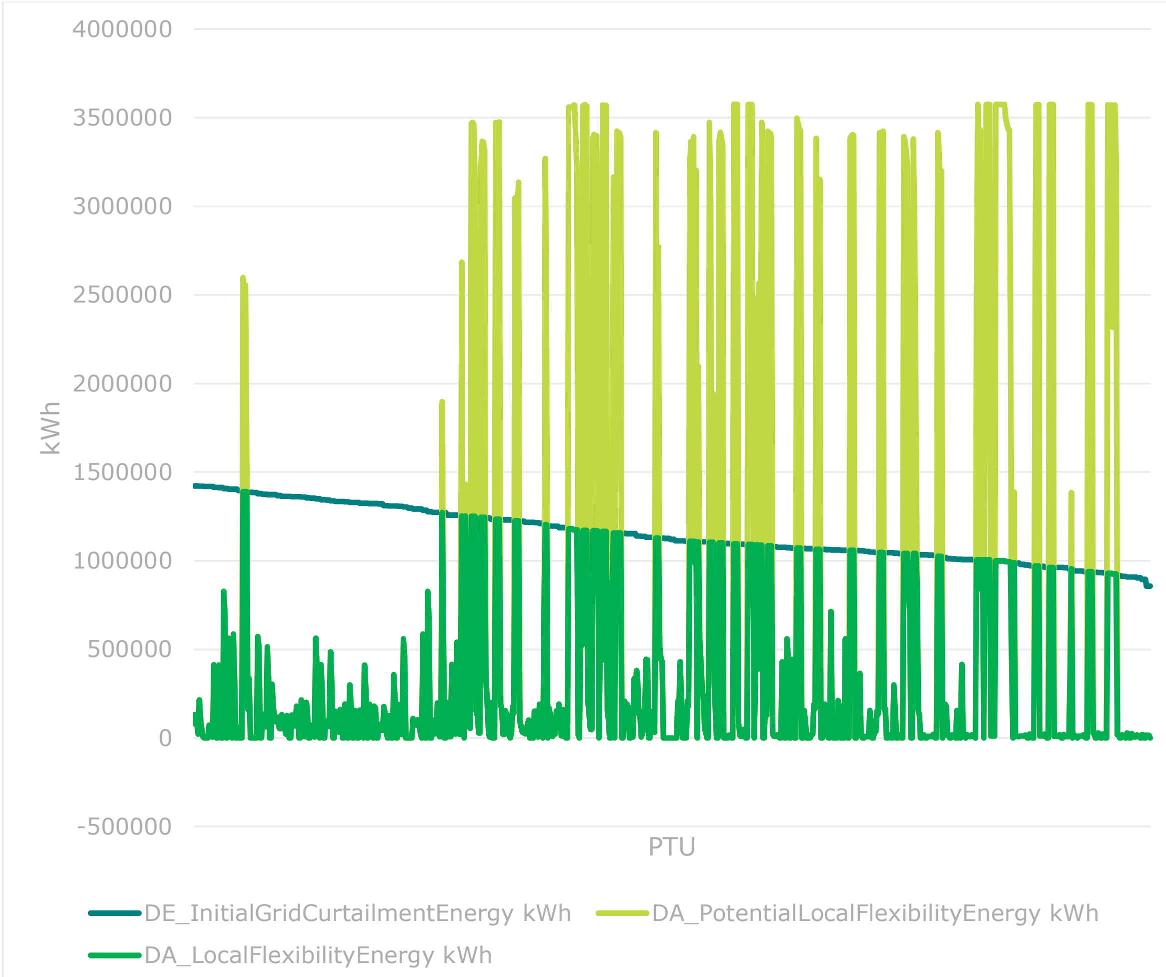

Figure 111: Local flexibility energy (HP1) ordered by descending flex request values

In this figure it is evident that there are certain PTUs in which three different situations occur respect to curtailment

- ✓ Fully mitigated: heat pumps mitigate curtailment completely, and in those PTUs the potential flex of heat pumps is much larger than the flexibility needs, so even a much larger curtailment could be avoided
- ✓ Partially mitigated: heat pumps just alleviate partially the initial curtailment
- ✓ Zero mitigated: heat pumps cannot provide curtailment mitigation because the thermal inertia is on its limit value

Which of these two behaviours is encountered depends mainly on the current capacity of the thermal inertia P_ThermalInertiaCapacity. When for a PTU this value is next to the P_ThermalInertiaTarget, and therefore the building can withstand a consumption decrease of the heat pump without producing an indoor temperature range violation, the flex provided mitigates completely the initial curtailment. But then, for the following PTU, the P_ThermalInertiaCapacity has been increased and if the flex request continues it will get to its the upper range P_ThermalInertiaSize and the heat pump cannot offer flexibility to avoid curtailment, because

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otherwise the internal temperature would get exceed UP_HighestAverageTemperature. The conclusion is that curtailment can be completely avoided for short flexibility requests (2-3 PTUs) but the more the average duration of the curtailment event the less the heat pumps will be able to mitigate it.

In the following figures we ordered the values by descending values of the DE_InitialGridCurtailmentEnergy/DA_LocalFlexibilityEnergy ratio, so that the differentiation of the two previously situations is evident. We did it for different penetrations of FHP heat pumps.

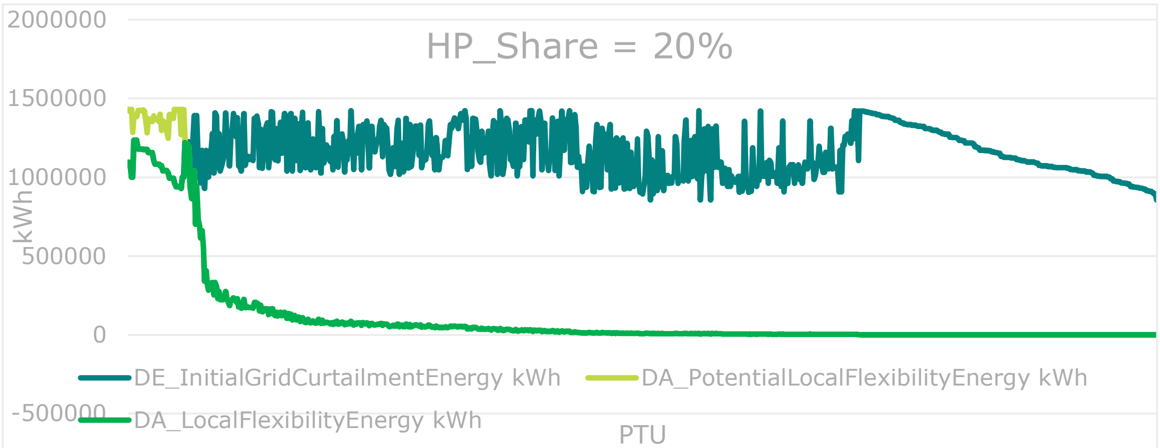

Figure 112: Evolution of local flexibility energy (HP_Share=20%)

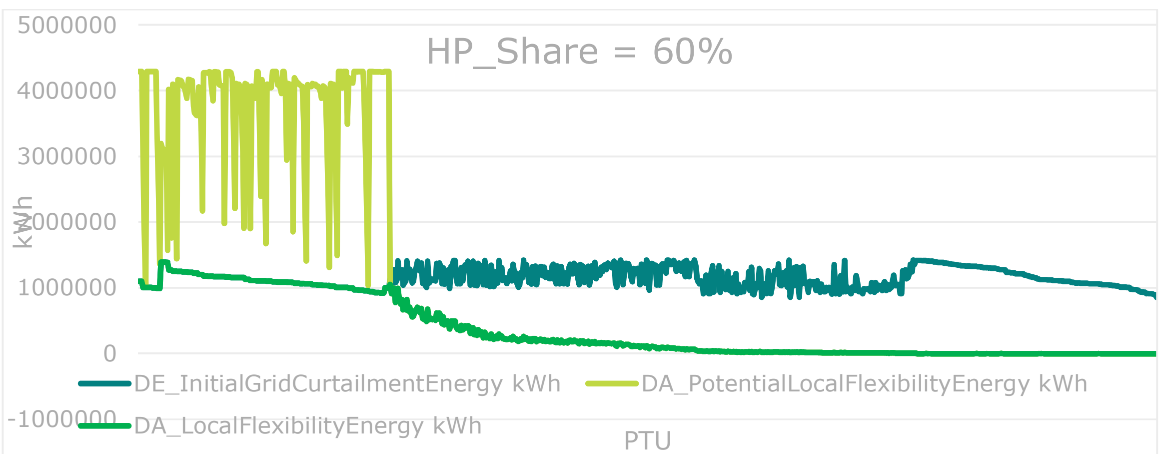

Figure 113: Evolution of local flexibility energy (HP_Share=60%)

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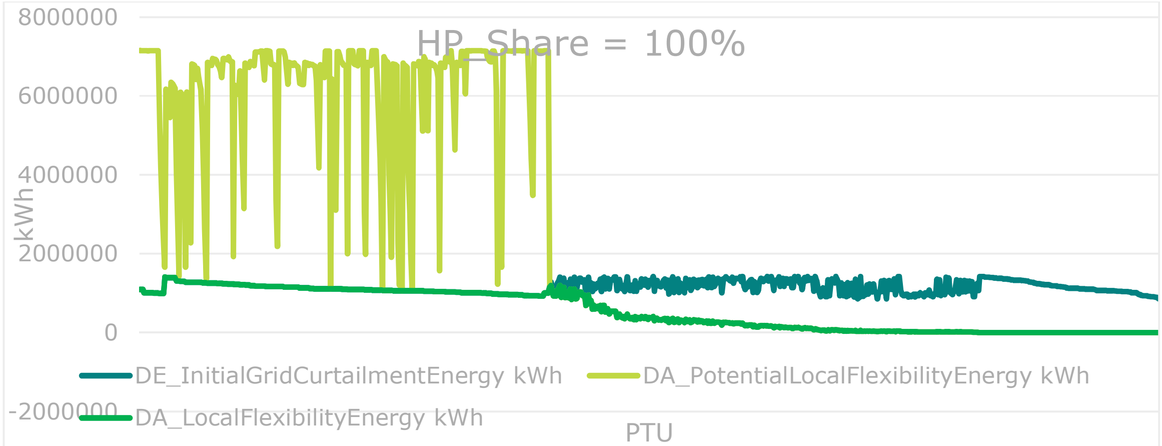

Figure 114: Evolution of local flexibility energy (HP_Share=100%)

Based on the profile of local flexibility energy, we model the different situations using these parameters to characterize both the energy curtailed (area representing number of occurrences multiplied by the energy involved) and the number of occurrences:

HP_Share	DE_InitialGridCurtailmentEnergy	DA_PotentialLocalFlexibilityEnergy	DA_LocalFlexibilityEnergy	DA_LocalFlexibilityEnergyFullyMitigated	DA_PotentialLocalFlexibilityEnergyFullyMitigated	DA_LocalFlexibilityEnergyPartiallyMitigated	Count DE_InitialGridCurtailmentEnergy	Count DA_LocalFlexibilityEnergyFullyMitigated	Count DA_LocalFlexibilityEnergyPartialMitigated	Count DA_LocalFlexibilityEnergyZeroIMitigated
%	kWh	kWh	kWh	kWh	kWh	kWh				
20	905.889.479	100.318.503	87.043.936	47.425.777	60.700.343	39.618.159	788	44	516	228
40	905.889.479	369.990.855	189.497.142	135.532.084	316.025.797	53.965.058	788	124	446	218
60	905.889.479	805.608.662	283.247.278	213.680.850	736.042.234	69.566.428	788	195	407	186
80	905.889.479	1.372.536.154	366.520.979	290.040.826	1.296.056.002	76.480.152	788	264	369	155
100	905.889.479	2.046.194.827	434.844.870	349.509.049	1.960.859.007	85.335.820	788	317	332	139

Table 40: Local flexibility energy characterization

For instance, with HP_Share = 100%, we get this simplified model for curtailment mitigation.

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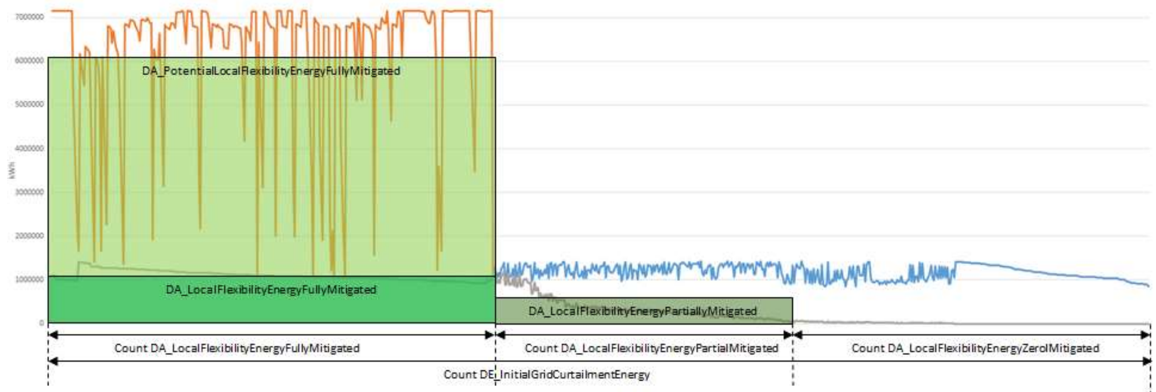

Figure 115: Grid curtailment mitigation model parameters for HP_Share = 100%

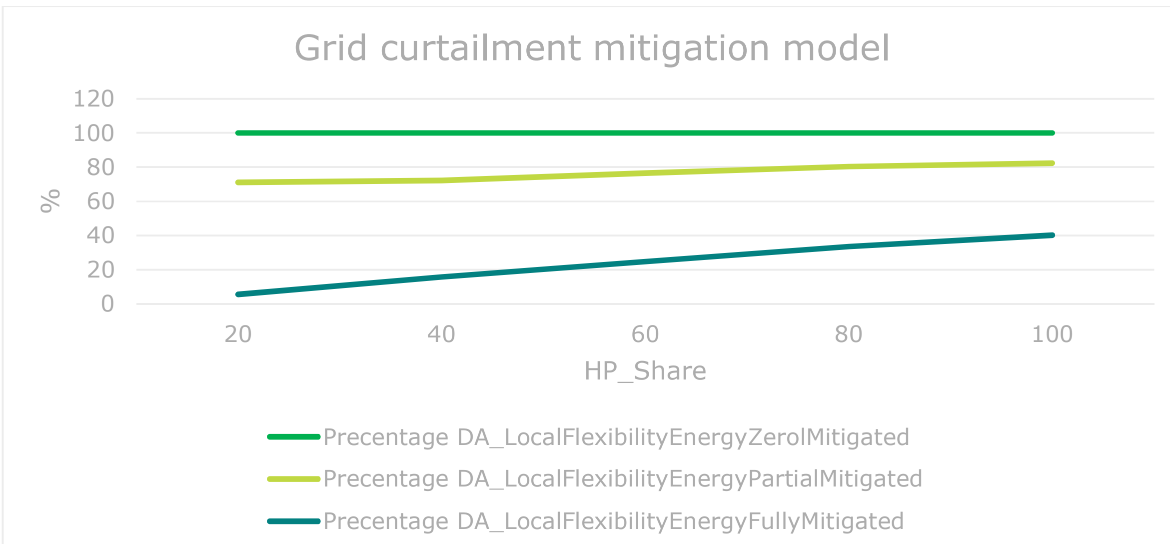

Figure 116: Grid curtailment mitigation model

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eHP_Share	Percentage DA_LocalFlexibilityEnergyFullyMitigated	Percentage DA_LocalFlexibilityEnergyPartialMitigated	Percentage DA_LocalFlexibilityEnergyZeroIMitigated
%			
20	6	65	29
40	16	57	28
60	25	52	24
80	34	47	20
100	40	42	18

Table 41: Local flexibility energy characterization

6.3.4.1.8 Conclusions

The assessment of the feasibility of the deployment of the FHP system has been positive. We have studied a short-term scenario where wind power capacity and heat pump penetration will be increased to deal with the target of decarbonizing the energy system, while heating demand and grid infrastructure will remain mostly unchanged. The result of the assessment because all active roles get a benefit due to the application of the FHP technology.

- ✓ The Heat User continues having the heating service provided by the Heat Provider at the same cost and the operation of the heat pump-based HVAC by means of a Model Predictive Control guarantees that the HVAC is operated under the comfort conditions agreed between the Heat User and the Heat Provider.
- ✓ The Heat Provider varies its baseline consumption profile due to flexibility provision, but it continues buying approximately the same yearly electricity amount to the retailer, so the electricity purchase cost does not vary substantially. Additionally, it pays to the Aggregator a service fee for participating in the FHP system, which is roughly half of the yearly incentives that it gets from the aggregator for the flexibility provided.
- ✓ The DER producer increases its yearly electricity production due to the decrease in the curtailment. But in economic terms, its income does not vary because it just swaps from an income due to the compensation of the DSO/BRP because of curtailment to an income of

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the retailer representing the Heat Providers which pays for the energy increase due to flexibility.

- ✓ The DSO substitutes part of the grid-based curtailment by flexibility buyed to the Aggregator. Because this mechanism to avoid congestion has an uncertainty, which will be solved in the settlement process, compared to the determinist act of curtailment, the DSO obtains a certain economic gain due to flexibility purchase.
- ✓ The BRP gets a two-folded benefit in the FHP scenario. On the one hand, it replaces commercial curtailment by flexibility paid to the Aggregator in UC2. And on the other hand, it uses real time flexibility from the Aggregator to act on its portfolio imbalance position in UC3. The ratio between the economic gain in UC2 and UC3 is 1 to 18 approximately, so the BRP is much more interested in buying flexibility for imbalance position optimization than for avoiding commercial curtailment compensations.
- ✓ The aggregator, which uses the incomes from both DSO and BRP to pay the incentives offered to the Heat Providers and which gets the incomes needed for launching its business, and for paying the FHP infrastructure, from the service fee paid by the Heat Providers.

It is also noticeable the different distribution of the execution of the use cases during the simulation period. Despite the prioritization of UC1 and UC2, due to the relatively low number of PTUs in which the conditions required to the execution of these two use cases are fulfilled, the flexibility provided is much smaller than in UC3. It is clear that even though the primary purpose of deploying the FHP technology is to mitigate renewable curtailment, as far as it implies a cost effective way to deliver demand side flexibility, the main revenue stream comes from a use case in which the system is purely operated for the economic benefit of the parties that are engaged in the business of providing flexibility (Heat Provider, Aggregator and BRP).

		UC1	UC2	UC3. Consumption decrease	UC3. Consumption increase
Flexibility requester		DSO	BRP	BRP	BRP
Requester cash flow	€	1.061.516	842.336	3.585.921	9.436.211
Flexibility price	c€/kWh	4,07	3,14	2,00	5,00
Flexibility provided	kWh	234.724.380	268.249.378	247.050.833	575.144.513
Number of executed PTUs		607	1061	4299	5346

Table 42: Summary of results per use case

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7 Conclusions

Today, curtailment remains one of the most significant challenges for renewable energy integration into systems with a deficit of flexibility options (e.g., flexible generation and demand), weak interconnections to other electrical systems (e.g., Spain), and/or where the implementation of necessary infrastructure has a slower pace than the one shown by variable renewable generation units (e.g., Germany). Under these circumstances, curtailment of renewable energy tends to be a useful procedure for system operators to guarantee network security.

Analogously, in those countries where zero or negative prices are observed frequently, RES curtailment is also a usual consequence of business logic.

In general, RES curtailment represents a lost opportunity. Every time clean energy is spilled society loses as a whole. Therefore, options to reduce or avoid curtailment should be explored. This opens the door for innovative business cases promoting the use of flexible resources that can provide services to a range of user groups. Take for example, thermal storage or heat pumps. These flexible resources can provide services to stakeholders in the electricity grid, while supplying heat to households, buildings or districts.

It is expected that the increase of RES capacity creates instances in which curtailment actions are needed more frequently, if increases in demand are not comparable and grid capacity (incl. interconnections) remains mostly unchanged. The increase of such instances, however, may also create a higher potential for local solutions (especially at distribution system level where location of resources is key for the solution of grid issues). If this potential is realised, then one can expect that grid losses at both transmission and distribution levels are also positively impacted (that is, reduced). This positive impact may even change the way network operators, mainly DSOs, plan and operate their grid.

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8 Catalogue of Business Use Case Functions

The functions can and will be catalogues in three classes:

- In-focus functions: Core functionality that will be implemented and tested (possibly multiple designs/implementations by different partners)
- Supportive functions: Functionality must be implemented to support the testing and demonstration of the in-focus functions. These will be implemented in an as simple as possible but sufficient manner to be able to test and demonstrate the in-focus functions
- Emulated functions: functionality that is out-of-scope and can be emulated, e.g., by reading/writing information to/from a file or database.

In focus functions	localRES CurtailmentMitigation	systemRES CurtailmentMitigation	balancing Services
DetermineGridZones	✓	✓	✓
UpdateHPContext	✓	✓	✓
CalculateP2HConsumptionProfiles	✓	✓	✓
DetermineHPConsumptionProfile	✓	✓	✓
DetermineHPFlexibilityInformation		✓	✓
DetermineDCMConsumptionProfile	✓	✓	✓
DetermineDCMFlexibilityInformation		✓	
DetermineDCMConstrainedFlexibilityInformation		✓	✓
UpdateDCMConsumptionProfile		✓	
UpdateLocalGridContext	✓	✓	
PerformGridSafetyAnalysis	✓	✓	

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CalculateLocalFlexRequest	✓	✓	
CalculateHPIncentives	✓	✓	
DetermineHPResponse	✓	✓	
CheckHPResponses	✓	✓	
CheckLocalFlexOffer	✓	✓	
DetermineHPConsumptionPlan	✓	✓	✓
DetermineHUSettings	✓	✓	✓
UpdateBRPPortfolio	✓	✓	
DetermineBRPUpdate	✓		
DetermineSystemFlexOffer		✓	✓
CalculateSystemFlexRequest		✓	✓
AdjustSystemFlexOffer		✓	

8.1 DetermineGridZones

Name	DetermineGridZones
Type	In-focus function
Actor	DSO
Description	Determine which connection points (associated with active buildings contracted by DCMs, non-active buildings and – RES – generators) belong to which grid zone.
Details	Grid zones are defined by the DSO as the collection of connection points that can be clustered together in a single virtual connection point for the grid safety analysis

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	algorithm. A grid zone could be part of a feeder, a complete feeder, a collection of feeders, etc. or it could be a single connection point. Using grid zones is a way to reduce the calculation complexity of some of the optimization and checking techniques that are used, but introduces additional aggregation/disaggregation functionality and complexity. Besides it may improve the accuracy of aggregated forecasts (forecasting errors of multiple Heat Providers e.g. buildings may even each other out).
Input	Depends on the strategy that is used (e.g. forecasts based on historical data for instance)
Output	Grid Zones (a list of which contracted connection points belong to which grid zone)
Preconditions	A grid model e.g. a complete description of the distribution grid, including cable length, cable material, insulation material, transformer properties, incl. list of all connection points (location) and their characteristics (max connection capacity, RES, etc.)
Comments	Grid zones may change depending on for instance season or time of day or weather forecasts. Different approaches and strategies can be applied to define grid zones, e.g. using forecasting and load flow checks, or machine learning for instance.

8.2 UpdateThermalContext

Name	UpdateThermalContext
Actor	In-focus function
Involved roles	Heat Provider
Description	This function collects and creates all additional information that is needed to calculate admissible (incl. optimal) P2H Consumption Profiles for the Heat Provider and the associated Heat Users.
Details	Specific information that may be collected (from other service providers), or created internally, could be weather forecasts, price forecasts, user behaviour, etc.
Input	-
Output	-
Preconditions	User behaviour model
Comments	This function may require to ask for / retrieve specific information from other sources (like forecasting services websites, etc.). These are not explicitly included in the Business Use Case UML schemes to not overload them.

8.3 CalculateP2HConsumptionProfiles

Name	CalculateP2HConsumptionProfiles

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Type	In-focus function
Actor	Heat Provider
Description	This function calculates a number of admissible P2H Consumption Profiles of Heat Users associated to the Heat Provider. Admissible consumption profiles are profiles that adhere to the comfort (specifically temperature) settings of the individual Heat Users.
Details	The Heat Provider (i.e., building) thermal response model (incl. HVAC model) is combined with latest Heat User settings (such as thermostat settings or flex offering settings that may have change) and other relevant Heat Provider Context information that is needed to calculate admissible P2H consumption profiles. This information is used by an algorithm that calculates control actions (hence consumption profiles) that adhere to the specifications and constraints of the P2H/HVAC system, and that adhere to specified comfort settings of the Heat Users.
Input	Heat User Settings Heat Provider Context
Output	P2H Consumption Profiles (electric)
Preconditions	Availability of Heat Provider (e.g., building) thermal models: considered to be a static model i.e. does not change (except maybe some model parameters may be recalibrated: this functionality is not included in the Business Use Case UML schemes to not overload them).
Comments	This function calculates a number of admissible consumption profiles for the Heat Provider (which may be a cluster of Heat Users). Multiple strategies can be used for that (multiple variant designs/implementations). For example, the Heat User (model) could auto-generate a number of profiles, or it could respond with a profile based on a request (e.g., shadow incentive signal) from the Heat User etc. Furthermore, the auto-generation of the Heat User (model) or the shadow incentive signals from the Heat Provider could follow specific tactics to generate the best profiles for the purpose.

8.4 DetermineHPConsumptionProfile

Name	DetermineHPConsumptionProfile
Type	In-focus function
Actor	Heat Provider
Description	The Heat Provider determines the optimal electric consumption profile based on the admissible P2H consumption profiles of the Heat Users, using some selection/aggregation and/or optional optimization strategy. On top of that, a forecast of the non-P2H consumption profile is added.
Details	The Heat Provider P2H consumption profile can be determined by multiple strategies. It can for instance be done by selecting the lowest cost admissible profile of each Heat User and adding these. But other objectives than cost could be used,

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	like minimizing energy consumption, maximizing consumption of renewable energy, etc. And instead of making a selection for each Heat User and adding these, this function could as well perform an optimization on the level of the Heat Provider (cluster of Heat Users) (e.g. for self-consumption or peak shaving).
Inputs	P2H Consumption Profiles Heat Provider Context information.
Outputs	Heat Provider Consumption Profile
Preconditions	Availability of functionality for forecasting the non-P2H consumption of Heat Users at Heat Provider level.
Comments	Multiple optimization strategies can be used (optimizing for cost based on forecasted prices is one example). Besides one can decide to select an optimal profile per Heat User and then aggregate these, or one can decide to optimize at aggregation level. This depends on whether this function contains an actual optimization or whether this is just a selection. Heat Providers could 'game' and for instance provide a too low Baseline Consumption Plan to the DCM, hoping to receive a request to increase consumption – and get paid incentives for that – later. This risk will be analysed and where possible counter-measures will be proposed.

8.5 DetermineHPFlexibilityInformation

Name	DetermineHPFlexibilityInformation
Type	In-focus function
Actor	Heat Provider
Description	The Heat Provider determines the flexibility it has. This flexibility can either be expressed as a delta 'band' with respect to an optimal Heat Provider Consumption Profile, or it can be expressed as a consumption 'band'.
Details	-
Inputs	P2H Consumption Profiles *Heat Provider Consumption Profile (optionally)* Heat Provider Context Information
Outputs	Heat Provider Flexibility Information
Preconditions	-
Comments	Multiple flexibility representations can be considered.

8.6 DetermineDCMConsumptionProfile

Name	DetermineDCMConsumptionProfile
Type	In-focus function

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Actor	DCM
Description	The DCM determines the optimal electric consumption profile based on the Heat Provider admissible consumption profiles, using some selection/aggregation and/or optional optimization strategy. This is aggregated per grid zone.
Details	The DCM Consumption Profile can be determined by multiple strategies. It can for instance be done by selecting the lowest cost admissible profile of each Heat Provider (Heat Provider Consumption Profile) and adding these. But other objectives than cost could be used, like minimizing energy consumption, maximizing consumption of renewable energy, etc. And instead of making a selection for each Heat Provider and adding these, this function could as well perform an optimization on the level of the DCM (cluster of Heat Providers) (e.g., for self-consumption or peak shaving).
Input	Heat Provider Consumption Profiles
Output	DCM Consumption Profile (aggregated per grid zone)
Preconditions	Grid zones are known. Balancing Groups are defined (considered to be static information that is known).
Comments	-

8.7 DetermineDCMFlexibilityInformation

Name	DetermineDCMFlexibilityInformation
Type	In-focus function
Actor	DCM
Description	The DCM determines the aggregated flexibility per balancing group of the contracted Heat Providers. This flexibility can either be expressed as a delta 'band' with respect to an optimal DCM Consumption Profile, or it can be expressed as a consumption 'band'.
Details	-
Input	Heat Provider Consumption Profiles *DCM Consumption Profiles (optionally)*
Output	DCM Flexibility Information (aggregated per balancing group)
Preconditions	Balancing Groups are defined (considered to be static information that is known).
Comments	Multiple flexibility representations can be considered.

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8.8 DetermineDCMConstrainedFlexibilityInformation

Name	DetermineDCMConstrainedFlexibilityInformation
Type	In-focus function
Actor	DCM
Description	The DCM determines the aggregated flexibility per balancing group of the contracted Heat Providers, taking into account local grid constraints (Flex Capacity Range). This flexibility can either be expressed as a delta 'band' with respect to an optimal DCM Consumption Profile, or it can be expressed as a consumption 'band'.
Details	-
Input	Heat Provider Consumption Profiles Flex Capacity Range *DCM Consumption Profiles (optionally)*
Output	DCM Flexibility Information (aggregated per balancing group)
Preconditions	Balancing Groups are defined (considered to be static information that is known). The Flex Capacity Range is either implicitly known from the last local flex negotiation, or it is explicitly asked to the DSO.
Comments	Multiple flexibility representations can be considered.

8.9 UpdateDCMConsumptionProfile

Name	UpdateDCMConsumptionProfile
Type	In-focus function
Actor	DCM
Description	The DCM determines the optimal electric consumption profile based on the Heat Provider admissible consumption profiles, using some selection/aggregation and/or optional optimization strategy. On top of that it also adds the (worst case) System Flex Request associated power profile (energy request → power profile). This is aggregated per grid zone.
Details	-
Input	Heat Provider Consumption Profiles System Flex Request
Output	DCM Consumption Profile (aggregated per grid zone)
Preconditions	Grid zones are known. Balancing Groups are defined (considered to be static information that is known).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731231

Comments	-

8.10 UpdateLocalGridContext

Name	UpdateLocalGridContext
Type	In-focus function
Actor	DSO
Description	This function collects and creates all additional information – next to the DCM Consumption Profiles that are received from the DCM – that is needed by the *PerformGridSafetyAnalysis function*.
Details	Specific information that must be collected and/or calculated/updated is: • Forecasts for/from generators specifically RES generators • Forecasts for non-active (i.e. not contracted by DCM) buildings. • Grid related info 'e.g., tap changer settings, …
Input	-
Output	Supportive information needed by the *PerformGridSafetyAnalysis function*.
Preconditions	Availability of functionality for forecasting the consumption profile on non-active buildings
Comments	This function may ask for / retrieve specific information, e.g., from the grid itself or from RES generation units and non-active (not contracted by DCM) buildings. These information exchanges are not explicitly included in the Business Use Case UML schemes to not overload them. For RES units associated with Heat Providers (buildings): their forecast is taken into account by the Heat Provider Consumption Profiles (which may be negative). This means that their forecast is taken into account by the *PerformGridSafetyAnalysis*, and that if such RES associated with Heat Providers would cause a situation that would result in (implicit and non-transparent, e.g., decided by the local invertor) congestions of such RES, this would be detected by the *PerformGridSafetyAnalysis function*.

8.11 PerformGridSafetyAnalysis

Name	PerformGridSafetyAnalysis
Type	In-focus function
Actor	DSO
Description	The DSO determines – based on the DCM Consumption Profiles and own forecasts – whether local grid problems (that would require local RES curtailment) are expected.

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Details	This function uses the grid model and up-to-date and forecasted grid configuration information (like tap changer settings) combined with baseline plans and forecasts to determine, if, where and when there would be a grid safety violation problem. Such a check typically could be done using a Load Flow Checking algorithm. For this check, the grid zones are used to simplify the checking and treat active and not-active buildings and RES generators as an aggregated entity (connection point to the grid) with associated grid constraints associated to this virtual aggregated connection point. The outcome of running the checking algorithm is the state (voltage, current, active power, etc.) of each grid zone (i.e., virtual connection point) for each time step of the checked horizon. These state values will be checked against the allowed safe values, and any violation will raise a flag to trigger a local flex request.
Input	DCM Consumption Profiles (aggregated per grid zone). Grid Context Information (incl. forecasts of RES and non-active buildings)
Output	A trigger to issue the formulation of a Local Flex Request
Preconditions	Grid model is available
Comments	-

8.12 CalculateLocalFlexRequest

Name	CalculateLocalFlexRequest
Type	In-focus function
Actor	DSO
Description	This function calculates a Local Flex Request per grid zone per DCM in relation to a (forecasted) local problem signalled by the *PerformGridSafetyAnalysis function*. These Local Flex Requests inform the DCMs about what flexibility the DSO is looking for to solve the (forecasted) local problem.
Details	A Local Flex Request consists of two parts. The first part describes when (which time step) the problem occurs and what minimal/maximal change in that time step is required to fix the problem *(e.g., increase consumption with min X max Y)*. The second part describes for all other time steps what the max allowed change is resulting from fixing the problematic time step(s) *(e.g., decrease consumption not more than Z)*.
Input	Problem formulation resulting from the *PerformGridSafetyCheck function* Baseline Consumption Profiles and forecasts for all grid zones
Output	Consumption or delta consumption (flex) band: minimum and maximum (delta) power consumption for every time step (per grid zone and DCM).
Preconditions	Grid model is available
Comments	If there are multiple grid zones, this will add significantly to the complexity, as choices that in a next step (calculating Local Flex Offers) are made for one grid zone,

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	impact what can be done safely in the other grid zones. Similar is true when there are multiple DCMs. We assume that any coordination will occur through the DSO, without peer-to-peer DCM interactions. There could be one flex request per grid zone (then all DCMs receive the same flex request for that grid zone) or there could be a specialized flex request per DCM per grid zone. Probably the initial request could be per grid zone (so same for each DCM) but as flex offers of DCMs are received, there may be differentiation (e.g., accepting the offer of one DCM, and only needing more iterations with another DCM). Instead of iterations of Local Flex Requests and Local Flex Offers, a market based approach could be considered as a variant. In such an approach, there would be no iterations, but based on Local Flex Requests (by the DSO) and Local Flex Offers (by DCMs) a market clearing algorithms would decide (this may result in no or only a partial solution). The Local Flex Request could be either expressed as a delta-consumption (i.e., flex) band, or as a consumption band.

8.13 CalculateHPIncentives

Name	CalculateHPIncentives
Type	In-focus function
Actor	DCM
Description	This function is part of a dual decomposition concept. It calculates Heat Provider Incentives (or financial signals) to invoke Heat Provider Consumption Profiles responses.
Details	As the dual decomposition concept is an iterative approach, the results of the previous iteration *(see CheckHPResponses)* can be used to calculate the Heat Provider Incentives for the next iteration, in order to gradually converge to the desired profile or band. At time steps where consumption must increase, the price is lowered. At time steps where the consumption must decrease, the price is increased. This way, it can be shown that successive iterations converge to the target profile.
Input	Local Flex Request (per grid zone) Result from the previous iteration
Output	Heat Provider Incentive
Preconditions	-
Comments	-

8.14 DetermineHPResponse

Name	DetermineHPResponse
Type	In-focus function

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Actor	HP
Description	This function is part of a dual decomposition concept. It calculates the optimal Heat Provider Consumption (power) Profile in response to the received Heat Provider Incentive.
Details	-
Input	Heat Provider Incentives
Output	Heat Provider Consumption Profile
Preconditions	-
Comments	-

8.15 CheckHPResponses

Name	CheckHPResponses
Type	In-focus function
Actor	DCM
Description	This function is part of a dual decomposition concept. It compares the aggregated Heat Provider Consumption Profiles that are received in response to the Heat Provider Incentives, against a target profile. This aggregation and checking is done per grid zone or per balancing group, depending on whether a Local Flex Request or a System Flex Request target profile must be matched. This to be matched target profile can either be a band, or it can optionally be a for the DCM optimal profile within this band. *(note: before the checking, also forecasts of the non-flex consumption must be added)*. If there is a (good enough) match the dual decomposition iterations can stop. Else another iteration will be started.
Details	-
Input	Heat Provider Consumption Profiles
Output	A flag indicating whether a (good enough) aggregated profile is received and the Dual Decomposition iterations can stop or not.
Preconditions	-
Comments	If an additional Dual Decomposition iteration is needed, the current aggregated profile result (as well as some specific additional analysis information) will be used as input for calculating better Heat Provider Incentives in the next iteration. In case no appropriate solution can be found (in time), an exception can be raised to exit the dual decomposition iterations and the DCM will conclude that no flex or only a part of the requested flex can be ordered to the DSO and code that information in the LocalFlexOrder. This exception is omitted from the Business Use Case diagrams to not overload them.

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	If there are be multiple DCMs active in the same Grid Zone, this will add significant additional complexity. Their flex offers will influence each other and some form of coordination is required. We assume that any coordination will occur through the DSO, without peer-to-peer DCM interactions (gaming risk).

8.16 CheckLocalFlexOffer

Name	CheckLocalFlexOffer
Type	In-focus function
Actor	DSO
Description	The DSO checks whether the received (aggregated) flex offers from the DCM(s) solve the forecasted problem. If so, they can be accepted and the flex orders can be placed. If not an adjusted flex request will be calculated.
Details	-
Input	Local Flex Offers
Output	A flag indicating whether the received (aggregated) flex offers solve the forecasted problem or not.
Preconditions	-
Comments	If an additional flex request iteration is needed, this maybe is only needed for a subset of the grid zones. If an additional flex request iteration is needed, the current aggregated flex offers (as well as some specific additional analysis information) will be used as input for calculating better next flex requests. In case no appropriate solution can be found (in time), an exception can be raised to exit the flex request iterations and the DSO will conclude that no flex or only a part of the flex can be activated. The result will be that RES will be (partly) curtailed. This exception is omitted from the Business Use Case diagrams to not overload them.

8.17 DetermineHPConsumptionPlan

Name	DetermineHPConsumptionPlan
Type	In-focus function
Actor	DCM
Description	The DCM determines the Heat Provider Consumption Plan (**<u>for the P2H resources</u>**) based on the received Local or System Flex Order.
Details	This function determines an optimal Heat Providers Consumption Plan based on the received Local Flex Order (safe flex power band) or System Flex Order (energy plan). These are disaggregated per grid zone (for local flex orders) or balancing groups (per balancing group).

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	This disaggregation itself can be based on the information that was used for the upstream flex offer aggregation which resulted from the dual decomposition negotiation between the DCM and the Heat Providers.
Input	Local Flex Order (per grid zone) or System Flex Order (per balancing group)
Output	Heat Provider Consumption Plan (per Heat Provider)
Preconditions	-
Comments	Besides a power profile schedule, the Heat Provider Consumption Plan could as well be an incentive signal similarly to what was used in the dual decomposition negotiation, or it could be a thermostat setting.

8.18 DetermineHUSetting

Name	DetermineHUSetting
Type	In-focus function
Actor	Heat Provider
Description	The Heat Provider determines the Heat User setting based on the Heat Provider consumption plan (update) corresponding to the received Flex Order.
Details	-
Input	Heat Provider Consumption Plan
Output	-
Preconditions	-
Comments	-

8.19 UpdateBRPPortfolio

Name	UpdateBRPPortfolio
Type	In-focus function
Actor	BRP
Description	The BRP updates his own consumption and generation forecast (DA/ID) based on the decided flex activations (updated baseline consumption plans). This way he can make better informed (updated) bids to markets.
Details	-
Input	BRP Update
Output	-

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Preconditions	BRP has forecasted information on the consumption and generation for its portfolio (in SystemRESCurtailmentMitigation, DA/ID) or for the system (BalancingServices, intra-ISP).
Comments	For the BRP Update information, it could be decided to either send only the decided flex activation (delta compared to the baseline consumption plan), or the updated consumption plan (updated baseline consumption plan)

8.20 DetermineBRPUpdate

Name	DetermineBRPUpdate
Type	In-focus function
Actor	DCM
Description	The DCM calculates per balancing group the effect of agrees flex activations resulting in consumption schedule updates that are decided DA/ID. This information is prepared to be provided to BRPs so these can use this information to make better informed (updated) bids to markets.
Details	This function disaggregates the Local Flex Order (or the decided optimal consumption profile that is consistent with the Local Flex Order) which is aggregated per Grid Zone, and aggregates it per balancing group.
Input	Local Flex Order
Output	BRP Update
Preconditions	-
Comments	For the BRP Update information, it could be decided to either send only the decided flex activation (delta compared to the baseline consumption plan), or the updated consumption plan (updated baseline consumption plan)

8.21 DetermineSystemFlexOffer

Name	DetermineSystemFlexOffer
Type	In-focus function
Actor	DCM
Description	The DCM calculate Flex Offer(s) for possibly multiple BRPs (using knowledge of balancing groups) based on the aggregated flex information from the Heat Providers.
Details	-
Input	Heat Provider Flexibility Information
Output	System Flex Offer

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research and innovation programme under grant agreement No 731231

Preconditions	-
Comments	There may be multiple different encodings and representations of flexibility. Examples are a set of alternative admissible traces (power profiles), or 'tank' models.

8.22 CalculateSystemFlexRequest

Name	CalculateSystemFlexRequest
Type	In-focus function
Actor	BRP
Description	The BRP calculates if, how much and when flex (i.e., consumption profile changes per balancing group) would be needed (to mitigate system RES curtailment).
Details	This function checks whether market based curtailment of RES would happen because there is a forecasted (DA/ID or intra-ISP) surplus of generation due to high amounts of RES, and for economic reasons the optimal decision would be to curtail RES. To mitigate this, the BRP will try to increase consumption and based on received System Flex Offers and the forecasted mismatch calculate an optimal System Flex Request.
Input	System Flex Offer
Output	System Flex Request
Preconditions	BRP has forecasted information on the consumption and generation for its portfolio (in SystemRESCurtailmentMitigation, DA/ID) or for the system (BalancingServices, intra-ISP).
Comments	There may be multiple different encodings and representations of flexibility. Examples are a set of alternative admissible traces (power profiles), or 'tank' models.

8.23 AdjustSystemFlexOffer

Name	AdjustSystemFlexOffer
Type	In-focus function
Actor	DCM
Description	The DCM recalculates/reshapes the System Flex Offer so that it does not conflict with the safe flex band specified in the DSO's Local Flex Order.
Details	This function is used when the DCM decides to support the DSO in avoiding a local grid problem. Therefore, he will calculate an updated System Flex Offer for the BRP, that fits within the constraints provided by the DSO.
Input	System Flex Request, Local Flex Order
Output	System Flex Offer

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Preconditions	-
Comments	There may be multiple different encodings and representations of flexibility. Examples are a set of alternative admissible traces (power profiles), or 'tank' models.

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9 Catalogue of Business Use Case Information Exchanges

Information exchanged ID	*Name of information exchanged*	*Description of information exchanged*	*Actors involved*	*Type*
IEX_01	Grid Zones	For each DCM: a list of which contracted connection points belong to which grid zone.	DSO to DCM	REPORT
IEX_02	Heat Provider Update Request	A trigger to ask for the latest Heat Provider consumption plan (and optionally flexibility)	DCM to Heat Provider	GET
IEX_03	Heat User Settings	Temperature, comfort and flexibility settings. E.g., thermostat programs, manual overrides, willingness to offer flexibility (temperature band versus a non-quantitative profile like normal/economical/ecological).	Heat Provider to/from Heat User	ASK/REPLY
IEX_04	Heat Provider Consumption Profile	Power profile (horizon, time resolution, power resolution, uncertainty, etc.).	Heat Provider to DCM	REPORT
IEX_05	DCM Consumption Plan	Power profile (horizon, time resolution, power resolution, uncertainty, etc.).	DCM to DSO	REPORT
IEX_06	Heat Provider Flexibility Information	There may be multiple different encodings and representations of flexibility. One possibility could be sets of alternative admissible traces (power profiles), or flex models.	Heat Provider to DCM	REPORT
IEX_07	DCM Local Flex Request	See USEF: for each grid zone for each DCM: a power profile band (time horizon, time resolution, power resolution) that specifies where when and how much flex must be activated, as well as delta	DSO to DCM	GET

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		constraints that must be taken into account so that no new problems will be introduced.		
IEX_08	Heat Provider Incentives	Price profile: euro value per time step (time horizon and resolution to be defined)	DCM to Heat Provider	GET
IEX_09	Heat Provider Consumption Profile	Power profile (horizon, time resolution, power resolution, uncertainty, etc.) of a Heat Provider.	DCM from Heat Provider	PUT
IEX_10	Local Flex Offer	Power profile (horizon, time resolution, power resolution, uncertainty, etc.) aggregated per grid zone	DSO from DCM	PUT
IEX_11	Local Flex Order	Power profile (horizon, time resolution, power resolution, uncertainty, etc.) aggregated per grid zone.	DSO to DCM	REPORT
IEX_12	Heat Provider Consumption Plan	Power profile that the Heat Provider must follow (possibly, this could be communicated indirectly by means price profile signal: euro value per time step)	DCM to Heat Provider	REPORT
IEX_13	Heat User Settings	Updated values for thermostat settings or a specific TBD information exchange with heat pumps (e.g. could be a specific power profile that the heat pump should follow).	Heat Provider to Heat User	REPORT
IEX_14	BRP Update	Per Balance Group the latest flex activations plan/schedule that is decided Power profile (horizon, time resolution, power resolution, uncertainty, etc.) aggregated per balance group	DCM to BRP	REPORT
IEX_15	System Flex Offer	There may be multiple different encodings and representations of flexibility. One possibility could be sets of alternative admissible traces (power profiles), or flex models	DCM to BRP	REPORT

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research and innovation programme under grant agreement No 731231

IEX_16	System Flex Request	There may be multiple different encodings and representations of flexibility. One possibility could be sets of alternative admissible traces (power profiles), or flex models	BRP to DCM	REPORT
IEX_17	Local Flex Order Accept	Flag	DCM to DSO	REPORT
IEX_18	Local Flex Order Decline	Flag (+ optional additional information)	DCM to DSO	REPORT
IEX_19	System Flex Request Accept	Flag	DCM	BRP
IEX_20	System Flex Order	There may be multiple different encodings and representations of flexibility. One possibility could be sets of alternative admissible traces (power profiles), or flex models	BRP TO DCM	REPORT
IEX_21	Flex Capacity Range	Power profile (horizon, time resolution, power resolution, uncertainty, etc.) aggregated per grid zone	DCM to/from DSO	ASK/REPLY
IEX_22	Imbalance (Price) Forecast	Price signals	TSO to BRP	TRIGGER

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