
 EUROPEAN UNION <small>European Regional Development Fund</small>		FED – Fossil Free Energy Districts
		Funding scheme: UIA – Urban Innovative Actions
		UIA 01-209
		Project period: 2016-11-01 – 2019-10-31

TECHNICAL FINAL REPORT

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ABBREVIATIONS

AH	Akademiska Hus, property owner at Campus
AWL	Active Working Lab – new name for JSP 2, future office building at Campus
C	Consumer
CFAB	Chalmersfastigheter, property owner at Campus
CO ₂	Carbon dioxide
CPC	Chalmers Power Central
DC	District Cooling
DSO	Distribution System Operator
DH	District Heating
EM	Energy Market
FED	Fossil free Energy Districts
FS	Flexibility Supplier
GBGE	Göteborg Energi
ICT	Information and Communication Technology
IKN	Local distribution network for electricity at Campus
IoT	Internet of Things
JSP1	Johanneberg Science Park 1, office building at Campus
JSP2	Johanneberg Science Park 2, see AWL
KB0	Local distribution network for cooling at Campus area
kW	Kilo Watt
kWh	Kilo Watt Hours
MC2	Building at Campus, Microtechnology and Nanoscience
MO	Market Operator
MW	Mega Watt
MWh	Mega Watt Hours
P	Producer
PCM	Phase Change Material
PV	PhotoVoltaic
R	Retailer
RFQ	Request for Quotation
SB1	Building at Campus, Architecture and Urban Design
SB2	Building at Campus, Civil Engineering
SB3	Building at Campus, Civil Engineering
SEK	Swedish Krona, currency
SO	Storage Operator
SSM	System Services Market
TBF	To Be Finished
TSO	Transmission System Operator
VP01	Local distribution network for heating at Campus area
WP	Work Package, refers to parts of the work performed in FED project as per project application

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I SUMMARY

Climate change is the greatest challenge of our time. Phasing out fossil fuels from the generation of electricity and heat is necessary and urgent. This transition towards 100 % renewable energy requires digital solutions for optimising and balancing the energy system. The high volatility associated with renewable, weather-dependent electricity generation puts a high demand on all players to interconnect and interact. This together with mega trends such as digitalisation and urbanisation as well as challenges with grid stability and distribution grid capacities provide the background and drivers for the Fossil-free Energy District (FED) project.

The purpose of FED is to meet these challenges and support the energy transition from fossil based to renewable energy by demonstrating scalable and replicable solutions within the areas of:

- Energy efficiency and smart energy management in public infrastructure and the housing sector
- Adoption of low carbon energy production and moderating the demand for heating and cooling
- Deployment of innovative, renewable-based solutions to heat/cool buildings and neighbourhoods.

The FED project is an innovative effort by the City of Gothenburg and has been funded by the European Union through the Urban Innovative Action (UIA) initiative. The project lasted between November 2016 and the end of October 2019. The local energy system and marketplace will be in operation until February 2020 in order to collect valuable data, and the project is open for knowledge transfer until October 2020.



The project group consisted of nine partners: The City of Gothenburg, Johanneberg Science Park, Göteborg Energi, Business Region Göteborg, Ericsson, RISE Research Institutes of Sweden, Akademiska Hus, Chalmersfastigheter and Chalmers University of Technology. The partners built a strong, local and multidisciplinary team for implementation.

In this project a digital market place was built and operated in a local energy system, encompassing more than 50 buildings and production units at the campus area of the Technical University of Chalmers in Gothenburg, Sweden. In addition, this local energy market is connected to and can provide services to the external networks, in this case the municipal district heating and electricity grids. Having an implemented market that operates in real time with three energy carriers on a relatively large scale is a major achievement.

The FED system has shown that it might be a possible solution to handle issues for a future energy market with an increasingly volatile energy production, need for increased flexibility and improved use of energy storage.

Results from simulations and actual operation indicate that the system can reduce peak loads and overall CO₂ emissions. Simulations show that the potential reduction of these can be in the order of magnitude of 20 % compared to a business-as-usual scenario. However, the results from the project indicate that FED as of today may not be a cost-efficient way to reduce CO₂ emissions or energy consumption.



In order to further develop FED and replicate this solution some key aspects that require more work are:

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- Standardisation for measurement, data collection and communication between buildings, technical installations, production units and interface towards an external digital market.
- More demonstration projects, to increase and share knowledge of local energy markets.
- Development of a clear and transparent business model and digital marketplace to ensure trust and financial incentives to all stakeholders.
- Updates and changes to current regulations and policies regarding local energy markets to allow for trading in local energy markets.
- Social acceptance is a prerequisite for a successful implementation. This means that any project looking to replicate FED must include working with social acceptance on several levels, for organisations, within the industry, policy makers, individual users and other stakeholders.

A large part of the FED project has also been to work with strategy for replication. This work has included studies to identify need for changes to regulations, technological barriers, roles and other social aspects but also providing recommendations for policy changes. This work has also included dissemination of results, lobbying activities and participating in more than 85 conferences, seminars, workshops, meetings etc. as well as receiving 37 delegation visits.

In addition to the technical parts and the replicability analyses of the project, FED has functioned as a testbed. Through this FED has helped to initiate more than 15 research projects (including academic research, master thesis and large EU funded projects), several innovative start-ups and the development of new concepts and solutions within the industry.

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2 INTRODUCTION

This report is a summary of the FED project and the aim and scope of this document is to summarise all deliverables in the project as well as the results. The basis for this document is the reports, outputs and different deliverables that have been produced throughout the project. These have been written by the participating partners within the project group.

In addition, there have been a number of studies and evaluations performed both by the partner group and by external parties, e.g. master thesis works. There have also been a large number of meetings, workshops and seminars that have contributed to the overall results of the FED project. As applicable, outcome and input from these have been included as part of this report.

Understandably for such a large, multidisciplinary project including such a variety of activities and innovative solutions, it is not possible to incorporate all details and outputs in one single document. This report aim to provide an overview and for anyone wishing to go into more details and in-depth analysis of any particular part of the project, please contact the partners that have participated in the project.

A background and introduction to the FED project are presented in chapter three. Chapter four, the technical description, present the FED system from a technical point of view. This includes the technical installations, the digital market place that is the heart of the project and the IoT solution that makes the digital market possible. Chapter five discusses business models for local energy markets in general and for the FED system in particular. Chapter six covers implementation and replication and goes into strategies and analyses regarding what is required for this to be possible. This chapter also includes the very important aspect of social acceptance and the need for regulatory and policy changes to make local energy markets feasible. Finally, chapter seven presents the results and discussion for the FED project and chapter eight gives the main conclusions drawn from the results.

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3 PROJECT BACKGROUND AND DESCRIPTION

3.1 Background to FED: Societal challenges, drivers and trends

The greatest challenge of our time is climate change and phasing out fossil fuels from the generation of electricity and heat is necessary and urgent. This transition towards 100 % renewables requires digital solutions for optimising and balancing the energy system. The high volatility associated with renewable, weather-dependent electricity generation puts a high demand on all players to interconnect and interact.

The price drop on solar PVs enables and entails new roles for property owners and energy companies. Local electricity generation and local energy systems need however to co-exist with the external energy systems for a secure energy supply, around the clock.

Digitalisation is a mega trend that has an impact in all sectors of society. It is an enabler through control, digital communication, prognoses based on whether data, artificial intelligence, Internet of Things etc. Digitalisation is a driver in itself and the energy sector has great potential for efficiency by embracing the new digital era.



Another current mega trend is urbanisation that puts higher demand on cities to provide its citizens with electricity, heating and cooling. Urbanisation, in combination with the electrification of mobility and industry sectors, gives an increasing demand for electricity and a demand of power in the place. Existing grid infrastructure currently face bottleneck challenges when transferring electricity into the cities and with increasing demand for both power and energy, these challenges must be tackled.

In a future fossil-free energy system, there will be an increased need for further contribution to grid stability. Along with increased digitalisation new opportunities occur for small scale generation units to participate in this contribution, both locally and nationally. A local energy market like FED can facilitate and make such local contribution possible.

The possibilities of sector coupling are widely discussed: how can the dependence of a specific energy carrier be avoided in favour of more flexibility for the user, and thereby use the price volatility on the energy market? Providing aggregated flexibility to grid operators, at different levels, is also frequently discussed but not proven in so many cases.

All these trends and drivers form a context in which a solution like FED may find its role as an answer to the challenges.

The FED project is funded by the Urban Innovative Actions (UIA) program within the European Union. UIA is an initiative of the Union to provide resources to urban areas, to test new and unproven solutions to address urban challenges. FED was granted funding in the first call in 2016, as one of three projects within the thematic area Energy Transition.

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3.2 Purpose of FED

Main purpose of FED is to address the energy transition challenges, discussed above, from a local energy system perspective. FED aims to take the lead on, and be a key component in, the making of the fossil free city.

FED supports EU in the challenges to drastically decrease the use of fossil-based energy, with a retained security of supply. FED creates prosumers and small-scale climate friendly energy production that strengthens the larger energy system. Increasing renewable production and reuse of local energy reduces external energy consumption and enhances safe and secure energy supply.

FED will support the energy transition challenge by demonstrating scalable and replicable solutions within the areas of:

- Energy efficiency and smart energy management in public infrastructure and the housing sector
- Adoption of low carbon energy production and moderating the demand for heating and cooling
- Deployment of innovative, renewable-based solutions to heat/cool buildings and neighbourhoods.

The FED local energy market will lead to growth and new business opportunities for entrepreneurs, prosumers, real-estate owners, utilities, suppliers and the ICT-sector.

As cities strive to become carbon neutral it is of great importance not to increase social inequality. FED creates cost effective energy improvement solutions, avoiding higher rental cost for economically disadvantaged citizens.



3.3 General project overview

The Fossil-free Energy Districts project, FED, is an innovative effort by the City of Gothenburg to decrease the use of energy and the dependence on fossil fuel in a built environment. A unique local marketplace for electricity, district heating and cooling is being developed together with nine strong partners.

FED will support the energy transition in urban areas by demonstrating scalable and replicable solutions for energy efficiency and smart energy management in public infrastructure and housing sector; the adoption of low carbon energy production and moderating the demand for heating and cooling; and deployment of innovative, renewable-based solutions to heat/cool buildings and neighbourhoods.

The project has run from November 2016 and three years until the end of the implementation phase in October 2019. The local energy system and marketplace will be in operation yet a few months, in order to collect valuable data, and the project is open for knowledge transfer until October 2020. The fossil-free local energy system, the digital FED marketplace and testbed has been situated on The Technical University of Chalmers' Campus Johanneberg in Gothenburg, Sweden.

The selected demonstration is located at a campus area with about 15 000 users. It has a well-balanced set of property owners, energy infrastructure and buildings with different needs and usage profiles. The area is exempted from the law of concession for electricity distribution, providing the opportunity to test and validate a local energy market. The prerequisites to optimise the use of primary or secondary energy using intermediate storage are well developed, as are they for generation, storage and distribution.

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The FED System solution aims to optimise the use of energy and local resources, by both taking into account the building usage profiles and the production profiles and making forecasts for both supply and demand. Thereby the system solution can match demand and supply and by using energy storage, flexibility and the possibility to switch between energy carriers it can reduce peak loads, optimise use of renewable energy and thereby lead to reduction of both costs and the environmental impact of the energy system.

The means to realise this solution is to create an IoT-based ICT-solution whereby physical assets (buildings, energy production units, storage units and distribution systems) are connected to a digital trading platform. By adding a forecast function, to both supply and demand for energy, and creating algorithms that optimise and make use of synergy effects, the ICT solution will allow for optimisation of the overall energy system leading to reduced costs and environmental impact.

The project also addresses the non-technical questions and challenges concerning local energy systems and trading. Social, legal, financial drivers and barriers have been investigated. Recommendations for changes in policy and a strategy for replication have been formulated. Business opportunities for various stakeholders have been touched upon.

During the course of the project, the area has been used as a testbed for companies to test and develop new, innovative products and services in the energy sector. The area and the FED project have been used as leverage to create new projects and start new initiatives in the thematic area.

3.4 FED objectives

FED aims to develop, demonstrate and replicate a novel district level energy system, integrating electric power as well as heating and cooling. The proposed solution contains advancements in system development and operation, business logics, legal framework as well as stakeholder acceptance. The objectives can be divided into three categories: FED demonstrator area and system solution, FED business solution – creating new sustainable markets and Dissemination and replication.



FED DEMONSTRATOR AREA AND SYSTEM SOLUTION

The selected demonstration is located at a campus with about 15 000 users. It has a well-balanced set of property owners, energy infrastructure, and users, including prosumers as well as buildings with different needs and usage profiles. The area is exempted from the law of concession for electricity distribution, providing the opportunity to test and validate a local energy market. The prerequisites to optimise the use of primary or secondary energy using intermediate storage are well developed, as are they for generation, storage and distribution.

Our solution will optimise the use of low-grade energy to replace primary energy. Adding fossil free energy sources while optimising different buildings usage profiles, one building's energy needs will be balanced with the surplus of another. Intermediate storage, fundamental to be success, consists of heating/cooling storage in the building's structure and batteries for electricity.

FED objectives connected to the energy and ICT system:

- Develop and demonstrate a microgrid, in full scale, serving about 15 000 end users, with 99.9% availability

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- Decrease fossil energy peaks 80%
- Decrease energy imported to the microgrid by 30%
- Develop and demonstrate, in full scale, an ICT service supporting future volatile energy markets
- Develop and operate an ICT-system for local energy trading, i.e. the technical backbone of a local marketplace co-operating with existing energy markets
- Develop, demonstrate and evaluate a new local energy marketplace, with at least 10 000 business transactions

FED BUSINESS SOLUTION – CREATING NEW SUSTAINABLE MARKETS

The success of FED depends on co-operation and energy exchange between several stakeholders. Business models for various actors will be investigated and the area will be made available as a testbed for actors outside of the consortium.



FED objectives connected to business development:

- Develop, test and evaluate new local market business models for 1) real-estate owners 2) utility companies and 3) end-users
- Develop additional innovative services through collaboration friendly 3rd party interaction activities

DISSEMINATION AND REPLICATION

At this stage of development, the prerequisites for scale-up and replication need to be addressed. There are knowledge gaps regarding local energy systems and their possible benefits, at all levels and among the variety of stakeholders. Therefore, objectives regarding dissemination and replication were formulated:



- Implement successful solutions from the microgrid in large-scale refurbishment and new city districts in Gothenburg
- Map the European market relevant for local energy solutions
- Present the FED solution to at least 50 European cities
- Become a demonstration site for smart microgrids. At least 100 external delegation visits, and displays at, as a minimum, 3 research conferences

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3.5 Project partner group and execution

The FED project group consists of nine partners: The City of Gothenburg, Johanneberg Science Park, Göteborg Energi, Business Region Göteborg, Ericsson, RISE Research Institutes of Sweden, Akademiska Hus, Chalmersfastigheter and Chalmers University of Technology. They are all contributing with their expertise and knowledge to make FED attractive for other European cities as well. Johanneberg Science Park has the coordinating role on behalf of the city.

The partner group provides an inter-disciplinary team with a wide range of competence and knowledge required to take on a project like FED. The innovative system solution requires technical knowledge and competence regarding buildings, energy production units, energy storage and distribution systems and the advanced ICT solutions required. Competence and knowledge about the non-technical aspects addressed in the project (financial, legal, social, business oriented etc.) is also vital. Finally, the partners represent a wide range of perspectives: academic/researchers' perspective, business perspective, both from real estate owners and an energy company, and the perspective of the public authorities.

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4 TECHNICAL DESCRIPTION

This section describes the system that was built and used for FED. A general concept and structure of the FED system is described, followed by more detailed descriptions of the parts making up the total FED system.

4.1 FED system – structure and conceptual description



The FED system can be said to consist of three parts: the physical assets (buildings, storage and production units), the market and the software or ICT solution that connects the physical assets and allow for trading of energy. These parts allow for an integrated view and connection of multiple energy carriers, in this case heating, cooling and electricity. How this integration is achieved is described in the sections below.

The buildings, production units and storage units that are part of FED are the actors on the market, it is here that energy is produced and consumed. This is the physical manifestation of the market and this is where the trading gets translated into changes of the production or consumption of energy through signals to the real estate owners control system that in turn changes valves, pumps, fans, boilers, heat pumps and so on.

The market is where the trading takes place, this is where the data input and bids get handled and energy is sold and bought. The market also include a possibility for trading System Services. This is the overlaying system that makes the FED system something more than a number of autonomous buildings and production units connected by distribution grids. The market is what shall allow for optimising the overall use of energy within the FED system and reduce peak loads as well as reducing costs and use of fossil energy.

The ICT solution are the programs and architecture that makes the market work, that handles trading and data. In addition this is the part that allows the physical assets to communicate with the market. One way to regard this is to see this as the enabler of the FED system.

Another way to describe the FED system is to structure it into these three parts: The Marketplace, Agents and Market Actors, as depicted in Figure 4-1. Each market actor, i.e. the physical asset, has a digital equivalent, an agent, that acts on behalf of the market on the FED marketplace.

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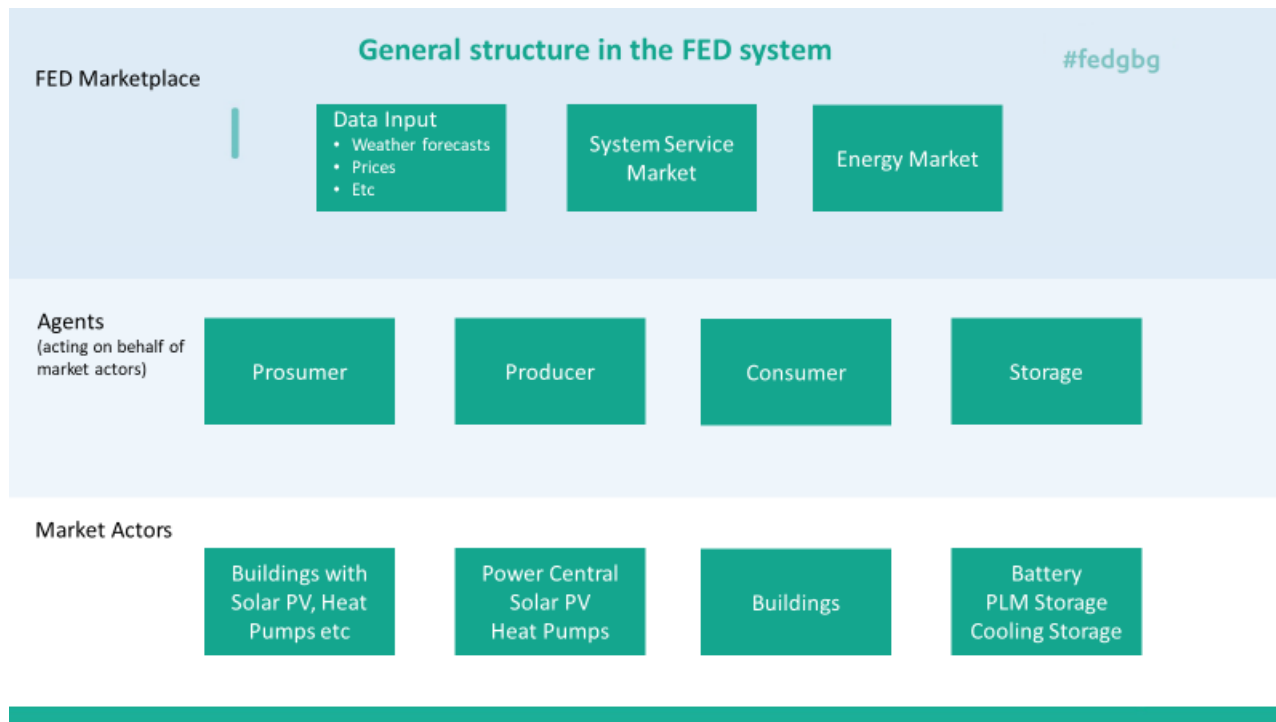



Figure 4-1 General FED structure.

This can be further broken down into a more detailed picture showing how the real estate owners control and monitoring systems are connected to Ericsson IoT Accelerator which in turn is connected to the FED marketplace, see figure 4-2.

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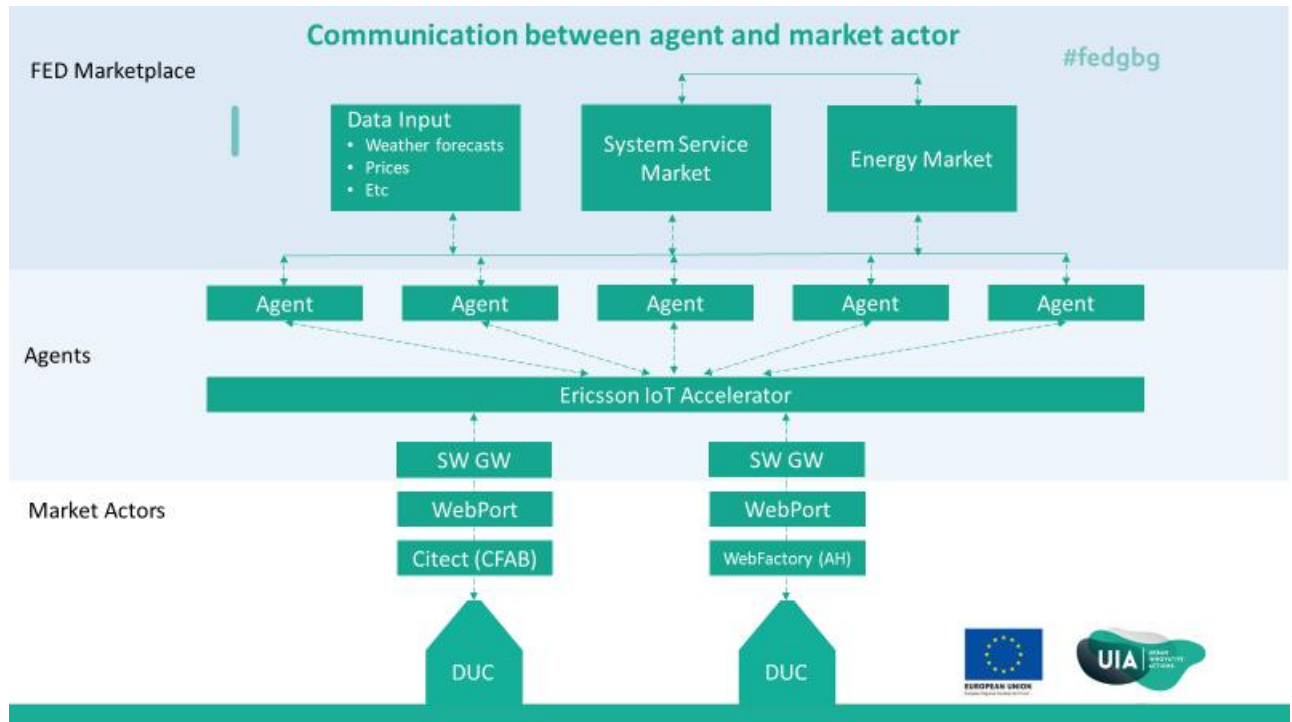



Figure 4-2 Communication between Market Actor and Market.

Figure 4-2 shows how the local controller in a building (DUC) is connected to the real estate owners overall control and monitoring system (Citect for Chalmersfastigheter AB and WebFactory for Akademiska Hus) which in turn communicates with the IoT Accelerator through a software gateway (SW GW).

This gives an indication of the complexity of the FED system; an overlaying market that is connected to each building, and even further is connected to individual sensors and valves within a building. The system must also be able to interpret all the data it receives and translate that into bids and services that can be traded on the market. The results from the trades must then be translated back into signals to a valve or set point for a sensor so that the digital trade is realised in the physical world. An illustration of this can be seen in figure 4-3.

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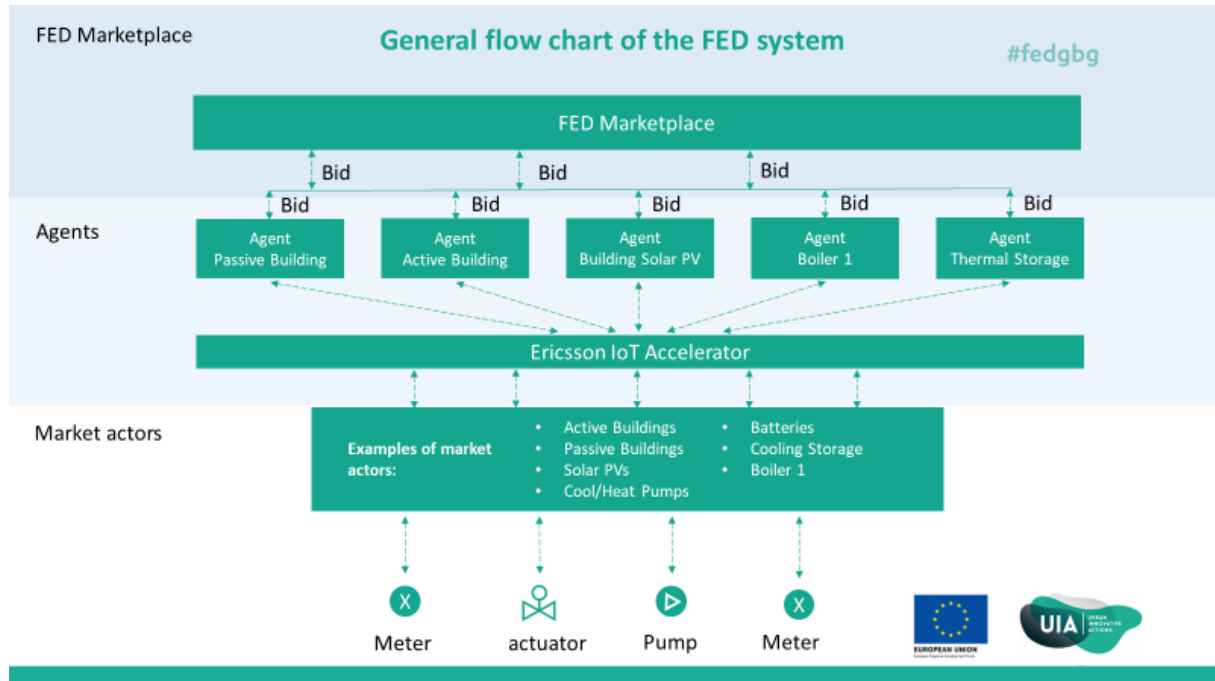


Figure 4-3 Flow chart for the FED system.

This figure shows the same communication as figure 4-2 but with the added detail of showing examples of what is sending and receiving data and information in the market actors.



What is a bid? Each agent submits a bid every hour for each trading period (1 hour) for the corresponding energy carriers. Each bid consists of a quantity of energy (kWh) and the corresponding value (SEK / kWh). These bids can be connected to each other in various ways using bid dependencies, which allow the agents to submit bids that reflect the flexibility that the agent can offer but also include limitations.

The market will then perform something that is designated as market clearing. This process means that the market determines the clearing price for each time period and energy carrier in such a way that supply and demand is balanced. To avoid bottlenecks and constraints in the system, both regarding production and distribution, this clearing price can be adjusted to take such conditions and constraints into consideration.

FED OPERATION EXAMPLE

As an example of FED in operation we can consider a building with advanced control system allowing the building to use thermal storage in the building structure to move its energy demand in time. This means that the building can provide a flexibility service to the overall market but also that it can move its energy demand to lower overall cost.

The building provides a forecast for the energy usage for the coming 10 hours which the agent translates into bids to the market, see figure 4-4. Each agent submits bids for the upcoming 10 hours, one bid per trading period. The bids for upcoming hours are expected to be updated if / when conditions change but unless the agent replaces or changes its bid it will be used at the corresponding trading period.

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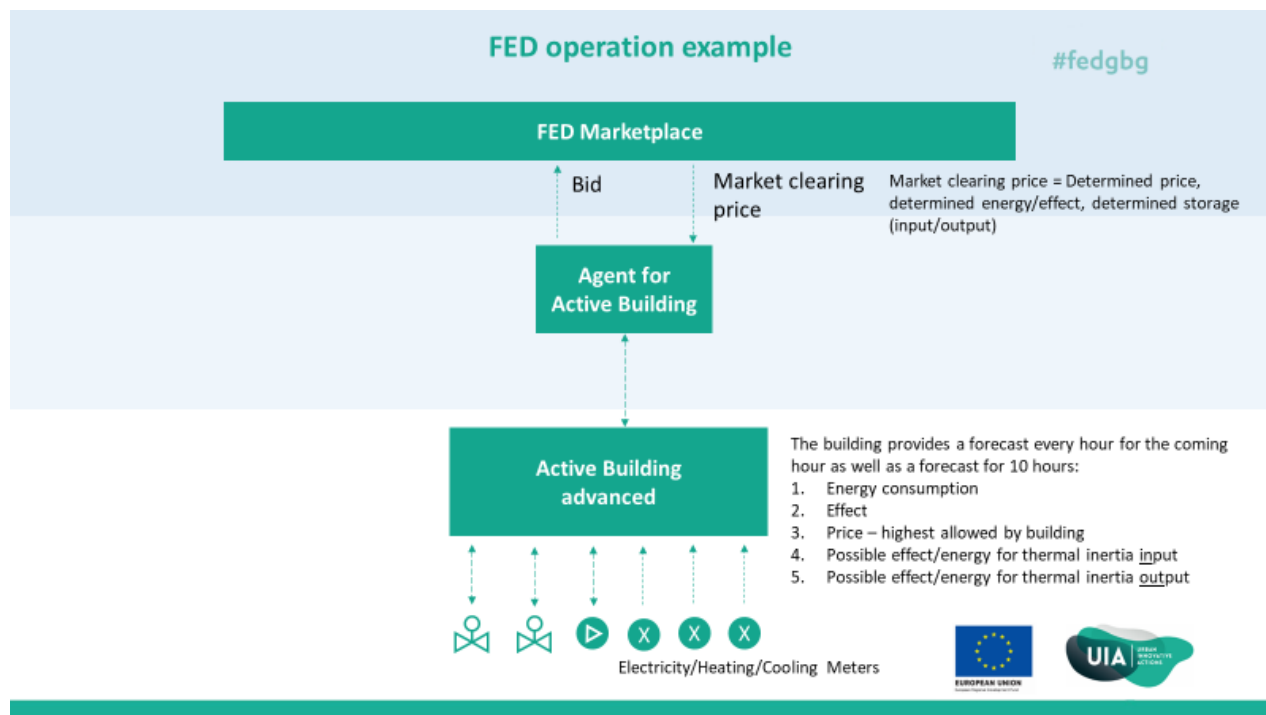



Figure 4-4 Operation example for building with advanced building control system.

The submitted bids from the agents provides a kind of overall forecast for the energy production and consumption, based on which the market will provide a forecast for the cost of the corresponding energy. The market operator can then see the difference in cost if it chooses to operate as normal or by moving the flexible energy demand in time, this is illustrated in figures 4-5 and 4-6 below.

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Normal operation

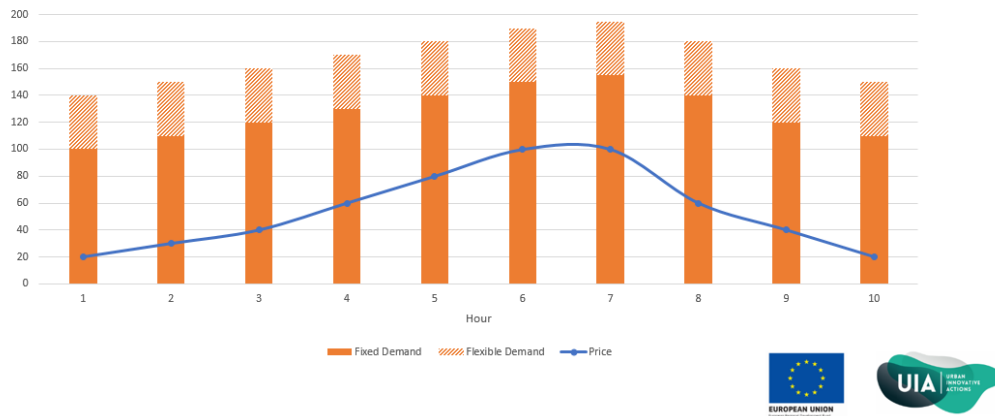


Figure 4-5 Energy demand and price for normal operation.

Move flexible demand to lower overall cost

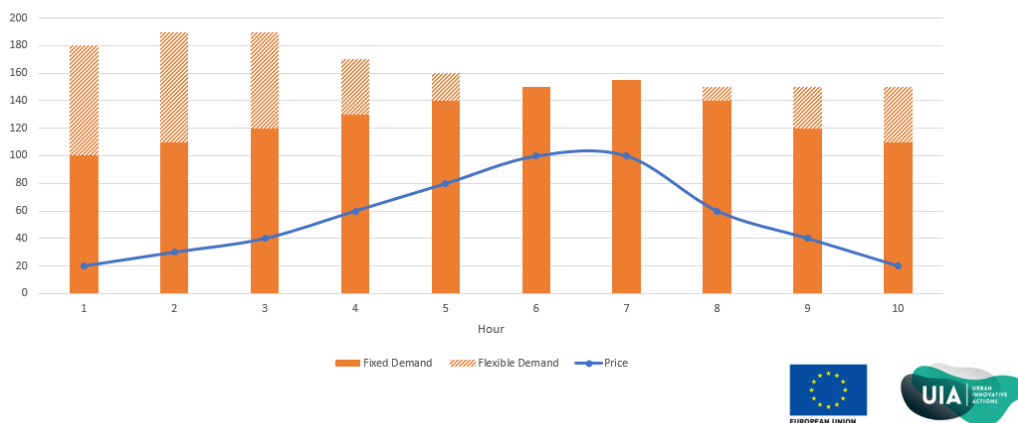




Figure 4-6 Energy demand and price when operating using the building thermal storage for flexibility.

This shows how the FED Market can allow a Market actor (in this case a building) to reduce the cost for its energy demand by using flexibility to purchase energy when the price is low. By setting the price to reflect CO₂ emissions or use of primary energy this can also lead to reduction of these.

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4.2 Market Design

4.2.1 Fundamentals

This section provides an overview of the design of the FED Market Place. The market has been positioned as a compromise between two extreme options: Central control of all resources and peer-to-peer transactions. This option has been chosen to balance the risks and advantages of both solutions.

One of the unique aspects of the FED market is that it includes three energy carriers (electricity, heating and cooling) that meet in the local energy market in order to exploit possible synergies. This is done by simultaneous and integrated clearing of the local market for all three energy carriers. Depending on the aim and application of the market the integration can be used to optimise use of local energy production, another application can be to focus on flexibility and trading system services. In the latter case integration may be less important.

In the FED system physical assets are connected and made available for trading with energy and services. A physical asset acting on the market is designated as a market actor (or market participant). A building with one or more production or storage units can be used as one market actor or several depending on the preference and interest of the owner. Each market actor is represented by an agent on the market place, this agent is a software representation that acts on the behalf of the actor. The agent optimises operations for the market actor and translates the operation into ask / bids to the market place.



Depending on the market actor the agent can have several roles. For instance a building that consumes energy but is also fitted with a solar panel to produce energy fills the roles of both “consumer“ and “producer” of energy, which can be combined to a “prosumer”. Some examples of the roles an agent can have on the market are:

- Producer – Supplier of energy, no net consumption
- Consumer – No generation of energy, only consumption
- Storage operator – Provides flexibility in terms of moving energy in time, e.g. battery storage
- Retailer – Provides energy from the external market

In addition to the FED energy market (FED-EM), the market design also includes the possibility to include a System Service Market (FED-SSM). Whereas the energy market is focused on matching supply and demand for energy a system service market could provide services for specific applications, such as voltage control in the electric distribution net.

Both the physical assets within the FED system and external stakeholders, such as retailers, have a link to the market place through agents. The local market participants, represented by local agents, asks / bids to the EM that also take in asks / bids from external markets through intermediate agents. The market facilitates coordination of resources at the local level and can play an active role in the external markets.

In order for the operation of the market to function properly there must be a responsible actor to ensure reliability and security, in FED this role is denoted FED Market Operator (FED-MO). The MO receives and controls the asks / bids so that they comply with the market rules and formats, execute the market

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clearing, defines prices, perform market surveillance and publish data on market operations. In addition, the MO is responsible that the local market complies with national regulations and market rules.

The owners of distribution networks are important stakeholders in FED. These networks facilitate the exchange of energy and are important for the system to be able to fully use synergy effects between energy carriers. Several distribution network operators can be included in the FED system, both for the local networks and the external systems.

One of the main driving forces for the Distribution System Operator (DSO) to participate in FED is to achieve an efficient operation of their system. FED can support that by taking into account grid constraints and grid state when clearing the market, external DSO can utilise the system service market to procure services for their system (e.g. flexibility).



AGENTS

Agents are an important aspect of the FED market and in general terms a market can be conceived where agents are not limited to trading only through the market place. Depending on the application of the FED system and local conditions there can be different possibilities for the agents to trade outside the market place.

The trading process for agents consists of the following steps:

- Preparatory steps
 - Forecasting & estimation
 - Bid/Ask submission
- Operational steps
 - Clearing
 - Execution
- Concluding steps
 - Settlement
 - Transaction management
 - Feedback & learning

The sequence is shown in figure 4-7.

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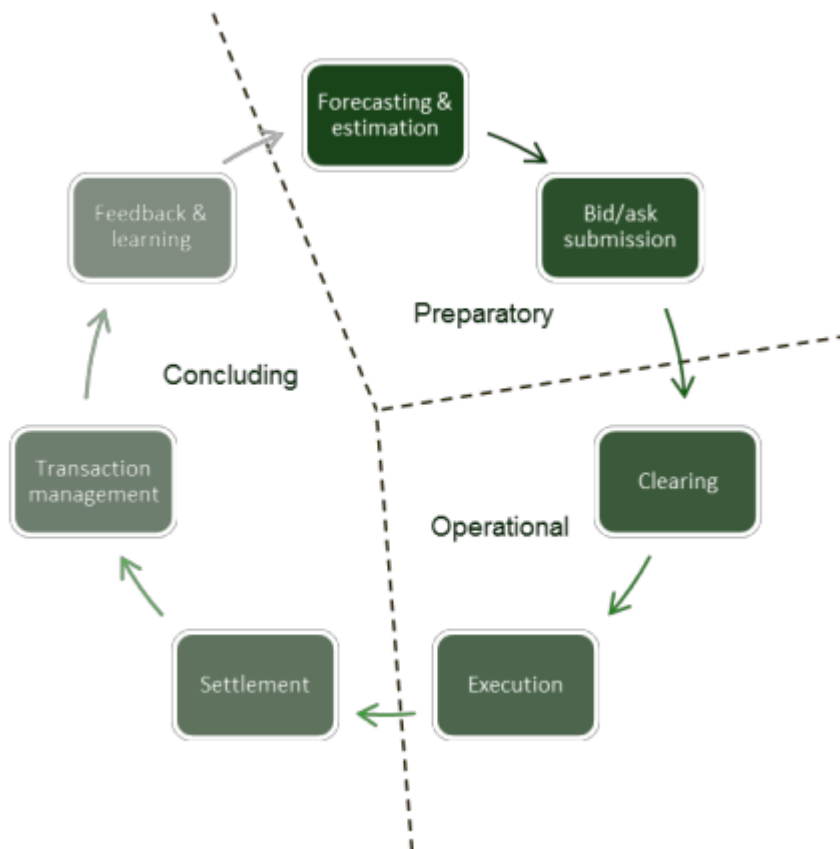




Figure 4-7 Agents trading process.

The preparatory steps include making a forecast or estimate of the agents supply and demand capacity, including any possibility to provide a flexibility in either supply or demand. Based on these estimates bids are generated and submitted to the markets. The forecasting may be quite complex, requiring gathering data on weather forecast, the current state of the physical asset, future market prices as well as estimating the demand for the physical asset itself.

The operational step of clearing is mainly a task for the market place rather than the agent, the agent receives information from the market place on which of the submitted bids that have been accepted and on market prices. Based on the received information the agent then executes the action, this means that the agent communicates with the underlying physical asset. The control system in the physical asset receive a signal and translates this into some control action (e.g. change of set-point value, valve position etc.). The operational steps are related to communication between agents and the physical asset.

The concluding steps include a settlement process where the imbalance between forecast and the actual demand / supply during the operational period is calculated and managed. The balance settlement is done by the market place and market operator but the agents receives data and information, similar as for the clearing step. The agents monitor and approve the transactions defined by the market place. The final step

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includes feedback to the algorithms for forecasting and monitoring and defining bids that can potentially enhance the accuracy and methods for performing new forecasts, estimates and decisions.

4.2.2 FED Energy Market


The commodity of the Energy Market (EM) is energy, production and consumption of energy as well as flexibility in terms of shift of energy supply / demand over time and the possibility to shift between energy carriers. The overall idea of the EM is to match supply and demand in order to use local resources efficiently.

Offers to the market consist of energy quantities and prices, including a bid structure that represents the available flexibility and the result after the market clearing consist of energy quantities and prices for the transactions. The trading and clearing if performed in trading periods defined by the FED-MO. The length of the trading period is decided by several factors, such as the capability of the metering infrastructure. For the FED project a trading period on one hour was used, this is a common length used for energy markets but for future applications and developments another length of trading period can be used.

The trading includes a number of trading periods in advance, the so-called trading horizon. The reason to include multiple trading periods is to allow the market participants to use the flexibility in terms of moving energy use in time to optimise energy use and avoiding peak loads. The trading horizon should be adapted to the needs and conditions of the where the EM is applied, for this project a trading horizon of 10 hours was used.

The EM applies clearing of the market in front of each trading period according to submitted bids. This is to mitigate errors in forecasting by allowing market actors to update bids closer to the delivery. This gives an advantage that estimates can be more accurate but can be a disadvantage for owners of larger production units since they can not plan their production far in advance. However, for FED systems with many small-scale production units this may not be a major issue.

One issue related to bids for future trading periods is how to incentivise the agents to provide accurate forecasts while also maintaining the possibility to adapt and update bids. For further development of the system this is an important aspect and the Market must provide incentives and control measurements that steer the individual market actor and agent towards the desired behaviour without discouraging market participation.

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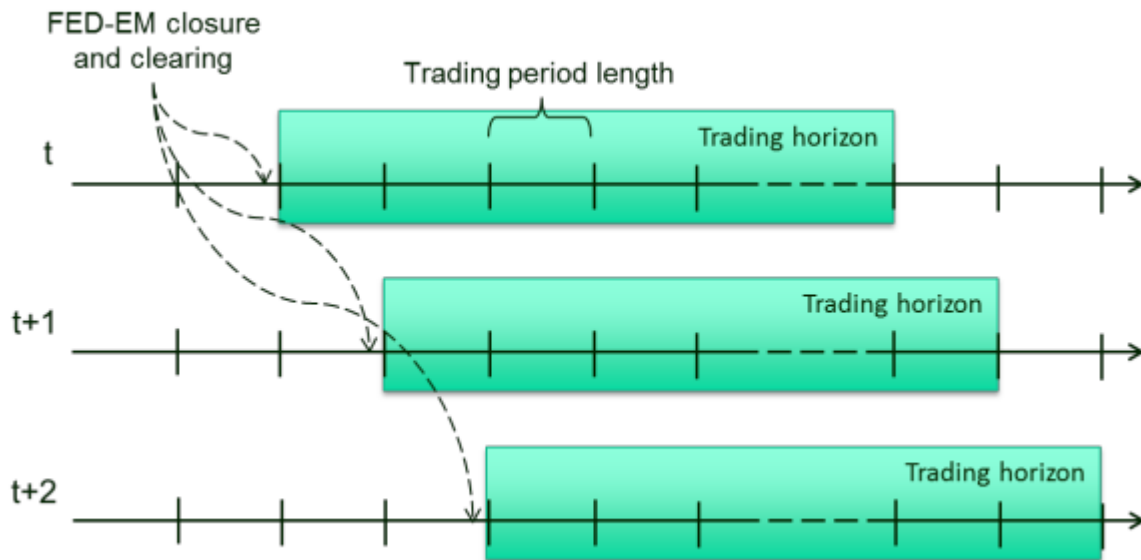




Figure 4-8 Time line for FED-EM showing trading periods, trading horizon and market closure and clearing.

The energy market is based on pool-based double-sided auctions. This means that asks / bids for both supply and demand are organised into aggregated demand and supply curves. This also means that market actors cannot choose with whom their transaction will be performed., the pool will either handle all transactions or choose which transactions will take place.

There is an interface between the EM and the agents, this consists of energy supply bids, energy demand bids and bid dependencies. The interface defines the parameters that can be included whereas the agent decides which of these to include in their bids. Supply and demand bids consider an energy quantity and price for specific trading period and energy carrier. The bid dependencies are a bit more complex, these include conditions for the bid. By keeping the bid dependencies a separate part of the agent – market interface it allows for agents to choose their level of complexity and thereby lowering the threshold for entering into the EM.

An example of use of bid dependencies is a building where a certain amount of energy is demanded but can be consumed at any time within a specific time interval. Demand bids can then be placed for each of the trading periods in the time interval, which then are complemented with a bid dependency defining that only one of these bids should be accepted. Another version of this is to state a certain number of demand bids with the bid dependency that the sum of accepted bids should equal a certain amount (being less than the sum of all bids).

The bid dependencies allow for a lot of possibilities to create market bids, it requires careful consideration and analysis of what possibilities that shall be allowed in order to ensure that the Market is steered towards its overarching aims and goals. Too complex or unrestricted bid dependencies may lead to that market clearing is not solvable whereas too many restrictions and limitations may lead to reduced flexibility and non-optimal use of local resources.

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The EM includes a representation, or model, of the local energy distribution system in order to manage congestion or other physical properties of the distribution grids that may be important for market clearing and pricing. The idea here is that any issues regarding capacity of the distribution grids shall be included as part of the market clearing instead of being handed over to the DSO after the clearing has been done and closed.

The level of detail of this representation can be tailored after the actual requirements and conditions of the local market but need to sufficiently detailed so that congestions and transfer limitations can be represented.

One of the most central tasks and responsibilities of the EM is to perform clearing of the market and calculating prices for the transactions to be performed as a result of the clearing. These tasks are performed by the market solver and are performed simultaneously. The submitted bids and data regarding the state of the infrastructure encompass the input that will be used by the market solver. The design of the solver has a crucial impact on the efficiency of the market therefore this aspect must be carefully analysed and evaluated.

The EM market solver is based on the micro economic theory, following that the aim of the energy market is to maximise the total system benefit which can be defined as:

$$\text{Total System Benefit} = \text{Producer Surplus} + \text{Consumer Surplus}.$$

As described above the market includes a model representing the distribution grids and to both reflect limitations in the grids and provide incentives for market actors to invest in flexibility and / or energy efficient measures, this is reflected in the pricing. Prices will thereby be dependent on:

- Geographical position in the system.
- Time.
- Energy carrier.



Another way to formulate the objective for the market solver is to state that it shall minimise cost. Depending on the complexity and functionality required of the market solver it can be more or less advanced. When designing this aspect of the EM the ambition should be to create a market solver that efficiently can solve the clearing problem, preferably using available methods and software.

4.2.3 FED System Service Market

The aim of a FED System Service Market (SSM) is to facilitate services related to the operation and management of the distribution grids and to provide services to the external market(s).

Grid services can include a wide range of commodities and service offers depending on the application and the considered energy carrier. The trades will also be relatively tailored towards a specific application. Another aspect of this market compared to the energy market is that it is often used to resolve technical issues or problems. As a consequence of these aspects the system service market have the following characteristics:

- Short time scales

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- Unpredictable demands

Technical challenges and issues regarding the distribution systems can appear on shorter time scales than the energy market. Also the demands for system services are likely to be unpredictable, most of the time there may be no need for services and it may be difficult to foresee when the need occurs. On the other hand, when the demand for a service occurs it may be both a high demand and an urgency. Based on these characteristics the SSM therefore is suggested to operate continuously, the main principle being that asks / bids can be provided and accepted at any time and on any time horizon.

During this project the potential for a system service market was identified and studied, furthermore the developed ICT solution and overall market design allows for the implementation and operation of a such a market. However, due to constraints in time and resources the SSM was not fully developed and implemented in the actual market in this project.

4.2.4 FED Market timeline and alignment with external markets

A challenge with local energy markets is to avoid sub-optimisation from the perspective of the energy system and market as a whole. Dividing the overall market into sub-parts where each part optimises their own use of resources can easily lead to such sub-optimisation. But local markets can also reduce the threshold for smaller actors to enter the market and contribute to the overall market.

To handle this, it is important to align the FED market trading timeline with the timeline for external markets. Other aspects that also need to be aligned concerns bid contents, quantity of energy and dependencies for bids. Figure 4-9 illustrates the trading timelines for EM and SSM.

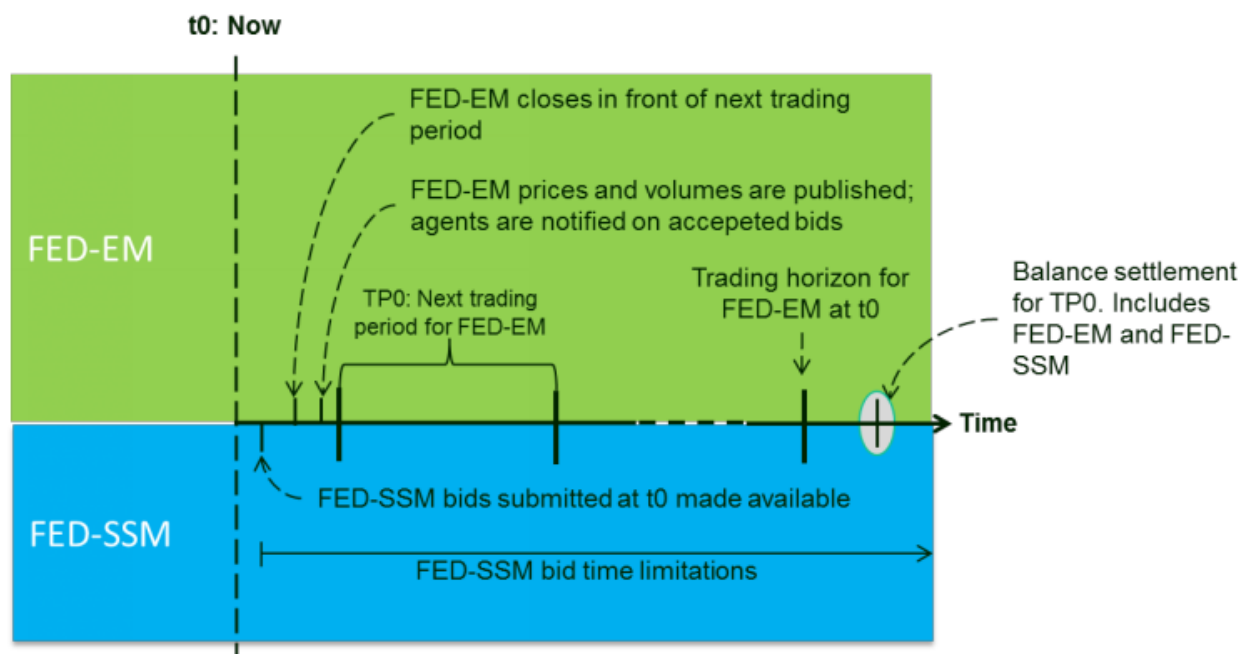




Figure 4-9 Timelines for trading on FED-EM (green) and FED-SSM (blue).

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For the FED project heating and cooling energy are aligned with the external market, in this case the district heating system owned by Göteborg Energi, who are one of the partners in the project. The alignment regarding time, contents, quantities and dependencies were based on existing agreement between Göteborg Energi and Akademiska Hus who owns and operates Chalmers Power Central.

For electric energy FED has been aligned with the Nordic electricity market with regards to timeline. The trading period applied on this market is one hour. The trading includes two market places where trading is performed beforehand, one real-time market and one aftermarket. The beforehand market includes bids and trading before the start of the actual hour, the real time trading is a balancing market for system services and the aftermarket handles transaction related to imbalances for each actor for the hours of the previous day.

The FED market place and the Nordic/Swedish electricity market shares the overall structure of having a beforehand market, a real-time market for system services, and a settlement process for imbalances. This facilitates possibilities for intermediate agents to be active on the external market and thereby link the local FED market with the external market for electricity. One difference between the two cases is the absence of a day-ahead market as e.g. Nord Pool Spot in the FED market. The FED market is instead operated as an hour-ahead market and thereby includes elements of the intra-day market at Nord Pool. However, the Nord Pool intra-day market does not include an explicit clearing function as FED-EM. Thereby, the overall function of FED-EM resembles a combination of Nord Pool Spot and Nord Pool intra-day.



4.2.5 Balance management and transactions

The trading on the market will result in a number of transactions that will take place. The trading is followed up with a balance settlement where the actual production and consumption is compared with the traded volumes. Any costs related to such imbalances are also subjected to transactions. This settlement process is the responsibility of the market operator.

Balance responsibility addresses the issue of balance management of the overall system with the aim to create incentives for actors to plan their operation and to perform forecasts so that they are in balance in terms of energy quantities per trading period. This means that, for a specific trading period, the sum of purchased energy and produced energy should be equal to consumed energy plus sold energy. To provide incentives for market actors to be in balance so called balance responsibility agreements with Balance Responsible Partners (BRP) can be used.

In FED the BRP is explicitly included, the FED market assumes that a BRP exists managing the imbalances towards the system operator on a national level according to existing legal arrangements. However, there are scenarios and applications where balance responsibility issues and conflicts can occur for a FED market.

With a FED market where agents can trade both in- and outside the market the agents production or consumption need to be separated and accounted for separately for trades within the market and outside. There must be mechanisms to ensure that an agent is not charged or compensated twice for the same traded volume. In addition, in such a case there is also an issue of how to handle costs incurred for the local market caused by trade between an agent and an external market. Such costs must be transferred to the actors in the local market.

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Another aspect that requires balance settlements is that the market must have incentives for agents to plan their operation and not exploiting strategic market behaviour by submitting inaccurate bids. Avoiding such behaviour is necessary for the market to work in an efficient manner.

The general process of calculating imbalance costs for the balance settlement is described in figure 4-10.

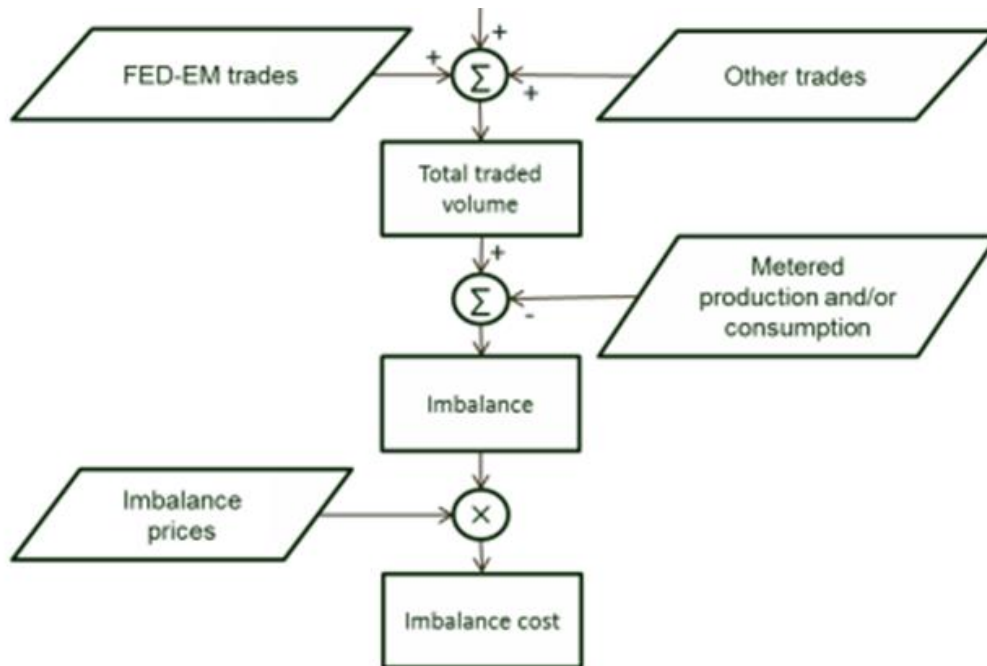




Figure 4-10 Flowchart showing process of settlement of imbalance costs. The label *Other trades* represents any trading that has taken place outside the FED Market.

An important aspect of the balance settlement is that metering infrastructure has the capability to retrieve energy data with the required time resolution. In the FED project the trading period is one hour and therefore the metering infrastructure must collect and provide accurate energy data on an hourly level.

The definition of the imbalance costs is of significant interest since this in turn defines the incentives for the market actors to perform accurate forecasts and trade accordingly, without exploiting strategic bidding. This includes both assigning costs that reflect the impact on the overall system and steers the behaviour of the market actors and, in addition, to correctly identify which actors that shall be subjected to penalties.

The method for the MO to calculate imbalance cost could differ depending on the application of the FED system, two possible approaches include:

- Imbalance costs are defined by the external market prices
- Imbalance costs are defined by standard fee or percentage of the EM prices

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The first approach means that the MO will collect prices from the external markets per energy carrier per trading period and use this as basis for imbalance costs. For heating and cooling such information may not be easily accessed or available.

The second approach means that the MO sets up predefined fees or factors to calculate imbalance costs. Such an approach require careful consideration since these fees can have a significant impact on the agent revenues/costs and thereby their willingness to act on the market.

4.3 Hardware – Technical systems and infrastructure

The FED system is situated at Chalmers Campus Johanneberg and includes buildings, production units and other physical assets on site. The project has mainly used existing infrastructure but also included a number of new investments in order to implement the FED system. Within the time and budget frames of the FED project additions such as new PV panels, heat-pump, heating and cooling energy storages have been made. There have also been investments in updates and additions to the control and monitoring systems. At campus



At the campus, other projects have been running in parallel with FED and investments made there have also been used in FED. For example, the PCM cooling storage and battery electricity storages have been financed by other projects. It is however important to remember, that the vast majority of the energy systems at the campus area, e.g. the district heating system, the power central with its boilers for heat production and some solar PV installations, existed already before FED.

Figure 4-11 below shows the campus area and the connected infrastructure that constitutes the FED project. Note that in the figure only production or storage units are included, in addition there are the buildings that provides energy storage (by thermal inertia of the building) and the consumption side of the FED system.



Figure 4-11 Connected infrastructure in the FED system.

Notes to figure 4-11:

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1. Solar PV Modules, connected to IKN network.
2. Boiler 1, producing heating, connected to VP01 network.
3. Absorption Chillers, producing cooling, connected to KB0 network.
4. Heating and Cooling Pumps, producing heating and cooling, connected to KB0 and VP01 networks.
5. Chiller system, with heat recovery, connected to KB0 network.
6. District heating connection from municipal network to VP01
7. Electric power connection from municipal network to IKN networks.
8. Battery Storage, connected to IKN network.
9. Heating and cooling pump, producing heating and cooling, connected to KB0 and VP01 networks.
10. Steam Boiler 2 and Steam Turbine, used for production of heat and electric power, connected to VP01 and IKN network respectively.
11. Quick-Charging Battery storage, connected to IKN network.
12. PCM Cooling Storage, connected to KB0 network.
13. Cooling storage tank, connected to KB0 network.

4.3.1 Buildings


The main bulk of market participants in the FED system, in terms of number, are buildings. The buildings connected to the FED system are where the energy is consumed, the demand side. The buildings on campus include offices, lecture halls, study areas, research facilities and some commercial areas, mostly cafés.

Buildings in FED can be divided into two categories:

- Passive
- Active

Passive buildings do not have any function where they can change or adapt their use of energy. Active buildings can take action in some way to adapt their use of energy, this is related to using the thermal mass of the building to store energy. In the FED system there are two levels of active buildings, advanced and simplified.

The advanced active buildings include a building management system (BMS) called EnergiVision (EVi), this is a smart system that optimises the energy use in a building. EVi uses measured data, prognosis and continuous energy storage calculations to control the technical systems in a building in order to minimise the use of energy. This building management system has been adapted and added to in order to utilise the EVi system in the FED project. These EVi buildings can adjust their energy use in time and thereby offer flexibility to the market.

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The simplified active buildings do not include any calculations or prognosis as part of its BMS. Instead, for these buildings FED is allowed to either shut down or adjust the set points for the heating system for a limited period of time. The length of the period and/or allowed off set for the set point values are based on input from the real estate owners. Based on experience and knowledge on how the buildings are used and function, the limits can be established. Note that such limitations and any dependencies should be adjustable to allow for trimming and optimising the operation. In addition, changing these values and limits can add flexibility and capacity for the storage of energy.

4.3.2 Grids

Akademiska Hus owns grids for heating (VP01), cooling (KB0) and electricity within the Campus, see figures 4-12, 4-13 and 4-14 below. These grids correspond to municipal grids for district heating, cooling and electricity. No additions or re-building have been done to the piping systems or electrical grid to allow for FED function.

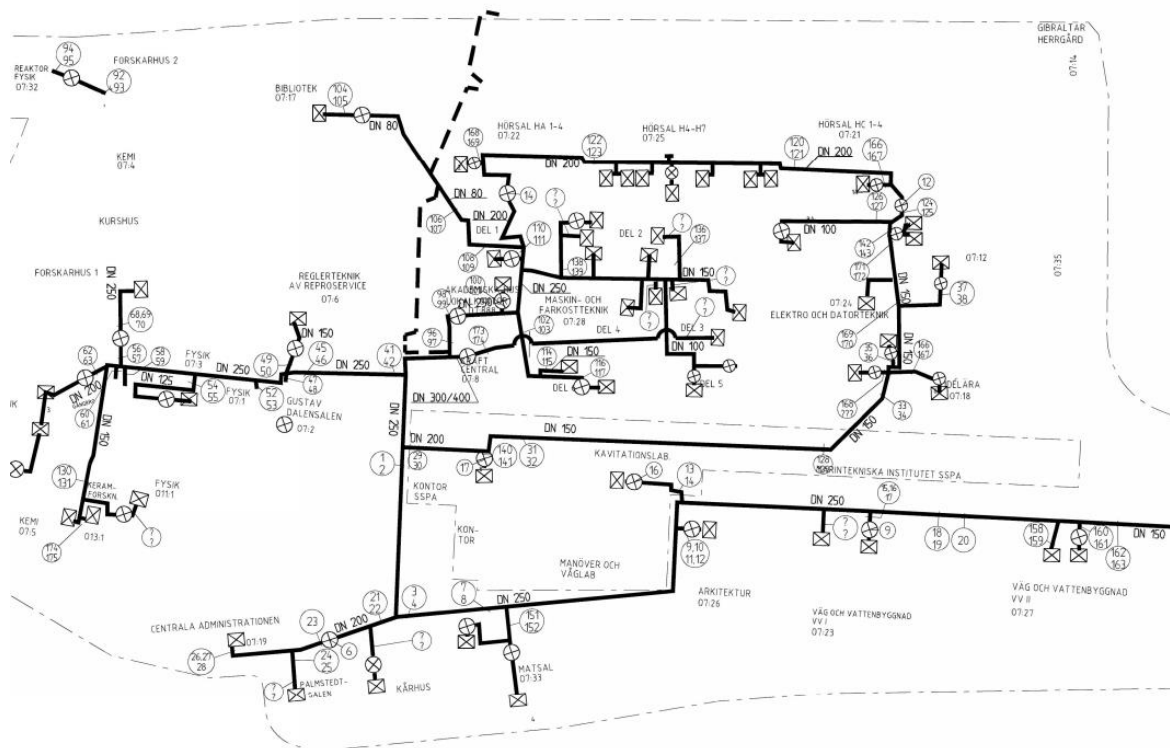
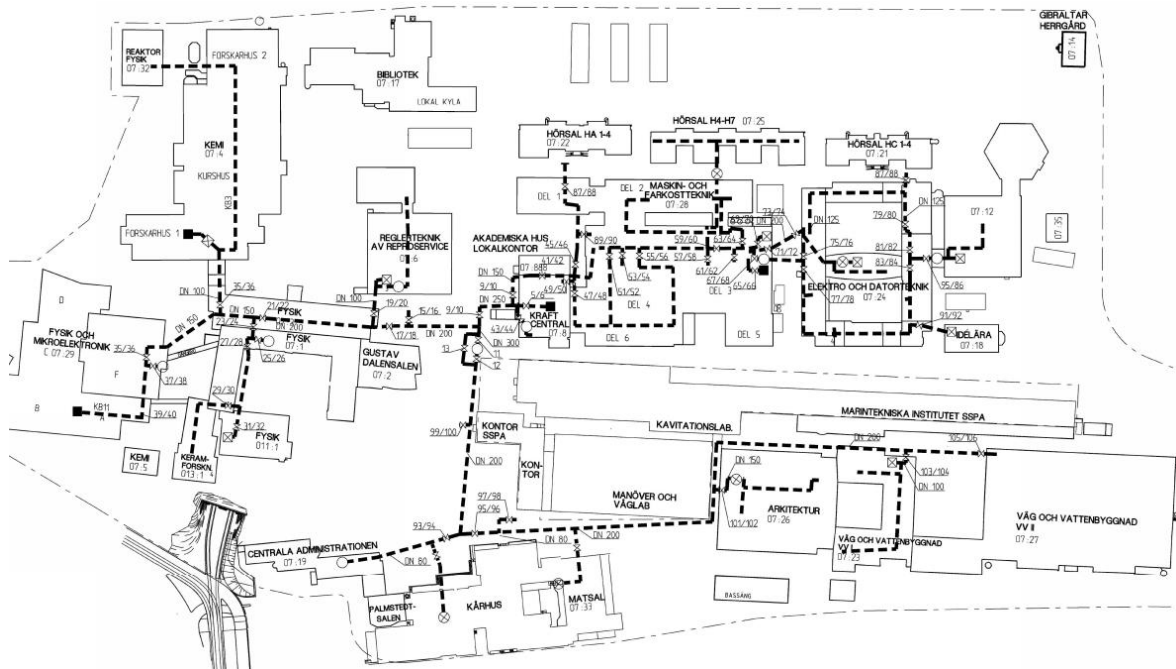


Figure 4-12 Heating distribution grid, VP01.





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There are also connections between the municipal electrical system (owned by Göteborg Energi) and the local distribution system, called IKN grids. In total there are 5 connection point within the campus area for electrical energy.



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Simplified storage systems uses only the normal existing heating system functions and hardware with no added measurement or monitoring.

Capacity and limitations

- 300 MWh stored heating energy
- 150 – 1 500 kW, loading / unloading heat power

Allowed storage is limited by temperature and comfort within the buildings. Starting point for FED is that temperature will only be allowed to change within the normal comfort range. It is possible to allow for greater flexibility and storage capacity (as well as lower energy use) by allowing larger temperature variations.

The flexibility for using energy storage in buildings is also limited by how precise the prognosis of expected heating and cooling demand is and how well the technical systems can be controlled based on that prognosis.

The advanced building control include both calculations based on machine learning to provide prognosis for the heating and cooling as well as possibility to adapt and control ventilation, heating and cooling systems based on the demand.

COOLING STORAGE

There are two cooling storages included in the FED system:



- PCM storage
- Cooling tank storage

The PCM storage uses material that changes phase between solid and liquid to store energy. This storage is built as part of a new office building on campus, AWL, and allows for loading of cooling energy from the KB0 grid and can unload cooling energy to the AWL building. In essence this storage will therefore function as a flexibility supplier to the AWL building.

The cooling tank storage consists of a tank filled with water used for cooling of machinery during testing / research performed at Chalmers. The tank uses cooling from KB0 to load the storage but can not unload cooling energy back to the KB0 system. This storage allows for pre-loading of cooling energy before expected tests. The storage thereby provide flexibility and can for instance be used to pre-load the tank when there is low demand for cooling in the overall system and by that reduce peak loads.

Capacity and limitations

- PCM storage:
 - 190 kWh, stored cooling energy
 - 37 kW, cooling power unloading
- Cooling tank storage:

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- 800 kWh, stored cooling energy
- 200 kW, cooling power unloading

The PCM storage can be used freely by FED and is not limited by impact on users in the building or that the storage is required to fulfil additional functions. However, the storage is limited by the cooling demand of the AWL building, if there is no cooling demand there is no use for the storage.

The storage tank is limited by the requirements for tests and research, the temperature in the tank must be maintained at a level that is sufficient for cooling of the engine or machinery being tested. Because of this dependency on the tests the effect or possibility for pre-cooling in turn depends on how well these tests can be predicted and planned in terms of cooling demand, length and time of tests.

BATTERY STORAGES

The FED project includes two battery storages:

- AWL
- Taking Charge

The AWL battery storage can load and unload electrical energy to the local electrical distribution grid. It is connected to the AWL building and is designed to allow for storage of surplus energy from the solar panels. This energy will then be used to run fans, lightning, hot water production and other smaller DC consumers within the building. FED can control and use this storage as part of the overall electrical system.



The Taking Charge battery storage can load and unload electrical energy to the local electrical distribution grid. It is designed as part of a charging station for electrical cars on campus. The battery storage can load and unload electrical energy to local electrical distribution grid.

Capacity and limitations

- AWL
 - 200 kWh, stored electrical energy
 - 75 kW, electric power
- Taking Charge
 - 200 kWh, stored electrical energy
 - 75 kW, electric power

When in FED operation the AWL storage can be freely used by the market.

Use of the Taking Charge battery storage is limited by its primary purpose to be used as a charging station for electrical cars. FED can load and unload electrical energy within set limits that ensures that there is sufficient energy in the battery for use in the charging station.

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4.3.4 Production

HEAT PRODUCTION

Heat production for the FED system consists of boilers, heating from the heating and cooling pumps and heat recovery from cooling units.

Boilers

There are two boilers at CPC, P1 and P2. The boilers function both as research facilities and as production units for the campus heating system.

P1 uses a fluidised bed for combustion and produces heat that is distributed through the VP01 distribution system. There is also a flue-gas condenser connected to this boiler that also produces heat. Surplus heat energy can be exported to the municipal district heating net. This boiler is in operation for approximately half the year.

P2 is a new boiler that produces steam, this steam will be used to produce electricity through a steam turbine. The steam will also produce heat to the VP01 system. Depending on operating mode this boiler can also produce 100 % heating and no electricity.

This boiler is a major new investment that adds to the overall capacity for the CPC, both heating and electric energy.

Heating and cooling pumps (VKA units)

There are three heating and cooling pumps. Two of these units were existing installations at CPC that produces both heating and cooling that is distributed through the VP01 and KB0 grids. As part of the FED project one new heating and cooling pump was installed, this allows for added flexibility in terms of production of heating and cooling.

One of these units are designed to operate during summer season to maintain the required temperature level in the VP01 grid while also providing cooling. The other two units are in operation during heating season where they produce cooling with heat recovery to the VP01 grid.



Since these units are connected both two the heating and cooling grids they can make use of local waste energy.

Heat recovery from cooling units

The cooling system in MC2 consists of 6 chillers and the heat from the condensers is recovered and used to heat the building. The recovered heat can not be distributed out to the VP01 net and used by other facilities.

Capacity and limitations

- P1, Boiler – 6 500 kW heating
- Flue gas condenser (P1) – 1 000 kW heating
- P2, Steam boiler – 6 000 kW heating

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- Heating and cooling pumps
 - 1 425 kW heating during winter
 - 800 kW heating during summer

The heat production in KC is a quite complex process and production of the respective units are dependent on each other. There are many limitations and set parameters that need to be considered for such a power plant with regards to FED.

There are limitations for FED control is based on minimum requirements for the overall heating system, e.g. that during summer there need to be a minimum temperature level maintained in the VP01 system that limits the allowed change in operation for the heating and cooling pump.

There are also limitations regarding how much and how fast FED can be allowed to change production, e.g. switching from production in P1 to importing district heating from the municipal grid. Power from the boilers need to be changed gradually and within set limits.

With regards to the heating and cooling pumps, in winter time there is also an interdependence with the requirement for cooling, these units must operate so that sufficient cooling energy is produced and can not reduce their production of heating unless this corresponds to reduced need for cooling from the consumers.

The two boilers (and the whole of KC) are also a research facility. This means that at times production from the boilers will be locked at a certain production power and time for research. At these times FED will not be allowed to change or adapt production of heating.

COOLING PRODUCTION

Cooling production for the FED system consists of cooling from the heating and cooling pumps at CPC and the MC 2 cooling system. In addition there are two absorption chillers located at CPC that are owned and operated by Göteborg Energi. These can be considered as district cooling from a municipal distribution system.

Heating and cooling pumps

As stated above there are three heating and cooling pumps at CPC.



During summer one unit is in operation and provides cooling with heat recovery to VP01 system. The main purpose of this unit is to provide heat and the main cooling is produced by the absorption chillers.

During winter all cooling to the KB0 grid is provided by two heating and cooling pumps, with the possibility to import cooling from MC2.

MC 2 cooling system

The cooling system for MC2 is divided into three sub-systems that provide cooling to different parts of the MC 2 building and facilities, including the clean room and research equipment. One sub-system provides cooling for the offices and this system can also export cooling to the KB0 system.

The MC 2 cooling have been updated and re-built to include a pump and valves to ensure that there is capacity to control and adapt the flow so that cooling from the MC 2 can be exported into the KB0 system.

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Capacity and limitations

- Heating and cooling pumps
 - 500 kW cooling during summer
 - 940 kW cooling during winter
- MC 2 export – 300 kW cooling
- Absorption chillers – 2 300 kW cooling

During summer FED can control the capacity of the heating and cooling pump and the remaining cooling load for the KB0 system will be provided by the absorption chillers (i.e. district cooling). There is a limitation in operation for the heating and cooling pump based on the requirement to provide heating to VP01 when district heating is not available.

During winter FED can control how much cooling should be imported from MC 2 but there is also a limit on how much capacity that is available from MC 2 based on the cooling demand within MC 2. This is regulated as a function of outdoor temperature. The remaining cooling load for the system is provided by the heating and cooling pumps.

ELECTRIC ENERGY PRODUCTION

Electricity is produced within the FED system by the steam turbine at CPC and by PV panels. Additional electricity is provided from the municipal electric grid owned by Göteborg Energi.

Steam turbine

The steam turbine is located at CPC and is connected to the new steam boiler (P2). The turbine itself has been fully renovated and updated to allow for automatic control of delivered power. The electricity generated by the turbine is distributed through the local IKN grid.



PV panels

There are a number of PV installations included in the FED project. All PV installations produces electricity to the IKN grid.

There are 3 installations that were in place and in operation before FED. These units can not be controlled by FED. In addition there are 7 new installations that have been constructed and installed during the FED project. For four of the new units additional control functions have been implemented financed by FED. The additional function allows for FED to control the reactive power output.

Capacity and limitations



- Steam turbine, G1 – 1 000 kW electricity
- Previously installed PV panels (3 units):
 - 108 kw, 92 MWh electricity

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- New PV panels (7 units):
 - 673 kW, 577 MWh electricity

When the steam turbine is in operation FED can control and change the power output within set limits. The steam boiler and turbine can change its output in steps and these incremental steps limits how fast FED can change the production and e.g. switch between producing electricity at CPC or importing from the municipal grid.

A number of PV panels have the added function that the reactive power can be controlled. The reactive power will be a commodity at the service market as part of FED. Naturally, the PV panels are limited by the solar irradiance.

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4.4 Software – ICT solution

The FED ICT solution is the software that will enable automatic trading of energy and energy related service. It connects the underlying physical facilities such as buildings, production units, batteries, and thermal storages with a central market. The different physical facilities or market participants will be represented on the market by a software based trading agent.

Due to time and budget constraints set by the FED project the ICT solution needed to regulate the complexity and level of final product. It should therefore be noted that the FED solution is not a commercial grade product but rather a proof of concept. However, the design and architecture of the ICT solution is such that it allows for adjusting the complexity and that the solution can grow into a commercial grade product.

4.4.1 Existing Architecture

The existing ICT architecture present at Campus was limited when considering the requirements to support the FED solution. The real estate owners control system included the following functionality:

- Akademiska Hus
 - Production facility control
 - Energy metering collection and storage
 - Sensor value collection and storage
- Chalmers fastigheter
 - Energy metering collection and storage
 - Sensor value collection and storage

Göteborg Energi had this functionality:

- Weather forecast collection and storage
- Energy price forecast collection, generation, and storage

In order to implement the FED solution Ericsson had to augment and add functionality to these systems to facilitate the connectivity and functionality required.

The real estate owners have their own IT or SCADA systems for control and energy and sensor value storage. Akademiska Hus uses WebFactory and UniView whereas Chalmersfastigheter uses Citect. These SCADA systems are central systems that in turn communicates with local PLC in each building or facility.

4.4.2 Solution Architecture

The FED ICT solution is composed of two main sub-areas and a vertical area for utility functions, see figure 4-15.



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Figure 4-15 FED Solution structure.

The market place contains the functionality of a market for different energy carriers & energy services, and the trading agents that trades on the market. It integrates with external data sources to bring in external forecasts and prices to the market.


The communication facilitates secure and managed collection of data and control of the underlying physical facilities that consume and produces the different energy carriers that are traded on the market.

The market place and communication areas shall support the trading of any number of energy carriers and related services, for this application the selected energy carriers are electricity, district heating and district cooling.

The vertical sub-area contains the functionality to survey and track the solution on a holistic level.

As the trading on the market will be fully automated there will be no end-user interaction apart from administration and operation.

The five subareas of the solution structure can be broken down into more detail in a logical architecture, as per figure below.

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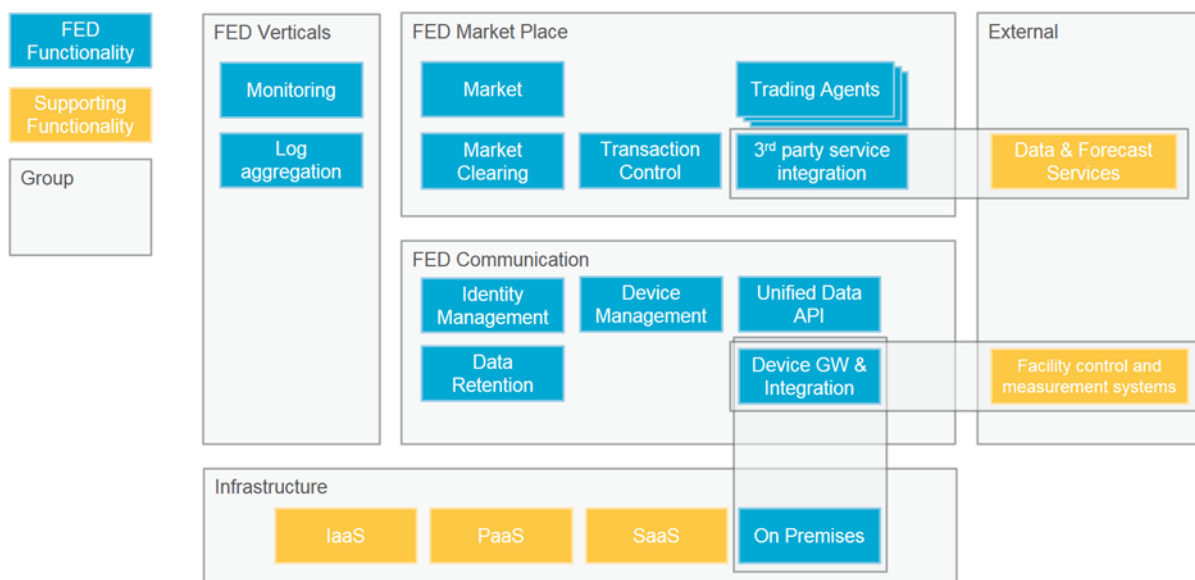


Figure 4-16 Logical architecture.

The market place contains the functionality for energy and energy service trading including the trading agents. It also integrates with functionality provided by the Communication and External subareas.

The communication subarea composes the functionality for connecting with underlying facilities. It integrates with external subarea and has a rigid binding to the on-premise infrastructure.



The verticals subarea includes the functionality for monitoring and logging of the ICT solution. It will integrate with the Market Place, Verticals, Communication, and infrastructure subareas.

The external subarea contains the provided service and applications that the FED solution will integrate and interact with.

The infrastructure subarea represents the IT infrastructure on which the FED ICT solution will be based.

FED MARKET PLACE

The market place contains the functionality to support trading of different energy carriers and their related services. An activity flow of the energy market is shown in figure 4-17.

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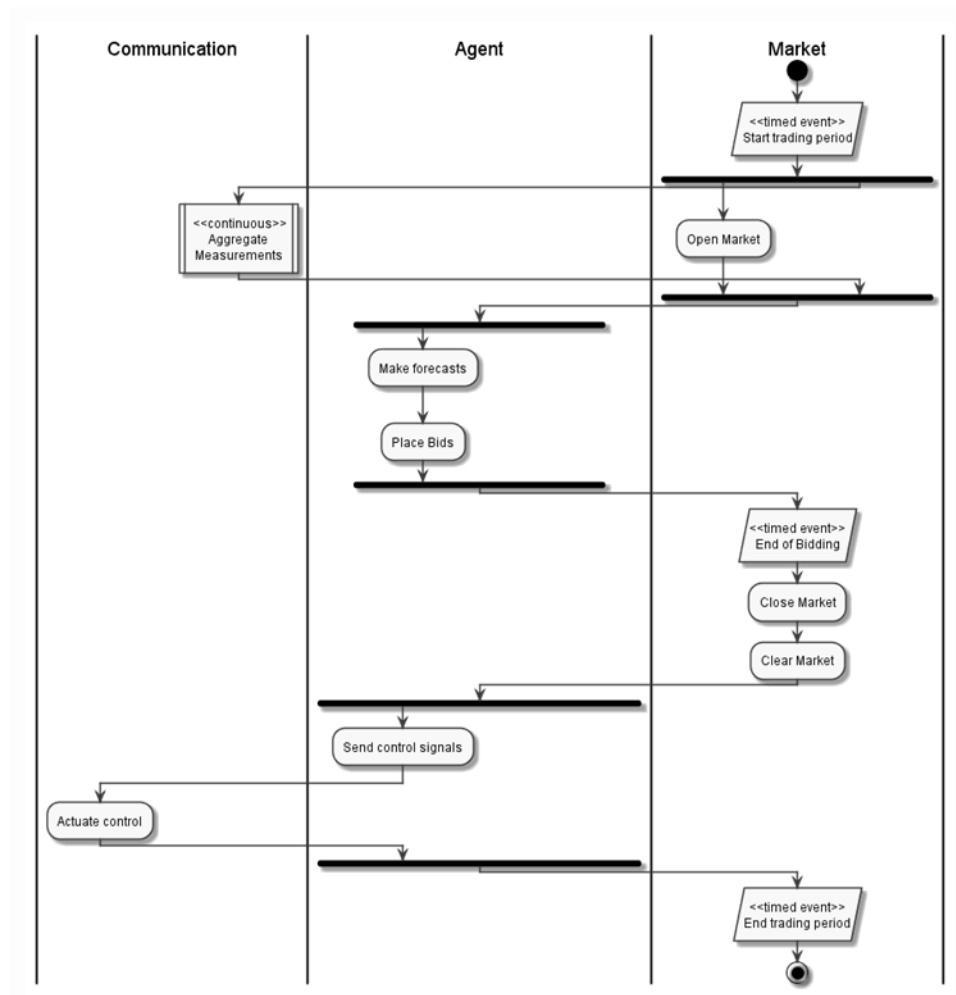




Figure 4-17 Energy Market Activity Diagram.

The energy market activity diagram presents a conceptual view of the activity flow in the market concerning the trade of energy.

1. The market runs in a time windowed mode, trading periods, at the beginning of each trading period the market opens to accept new bids from the trading agents, it also continuously collects measurements and readings from the underlying facilities using the functionality provided by the communication subarea.
2. Once the market has opened the previous trading period has by necessity closed, this triggers the settlement of the transactions that took place during the previous trading period. The trading agents will during the market open time make or update their forecasts for the coming trading periods and place bids accordingly.

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3. At a discrete point in time before the end of the trading period the market closes and does not accept new bids. At this point the market clears by matching the production and consumption bids and weighing physical limitations and environmental factors.
4. The agents use the result of the clearing to control their facilities and for the billing to log commitments.

The market place includes all the functions required for receiving and validating bids, control of the market, clearing, billing and transaction control. The market place also includes the trading agents that represents the market participants (market actors) and provide all or some of the following functions for each relevant energy carrier:

- Place demand / supply energy bids
- Place conditional dependencies between bids
- Place sell and buy bids on the service market
- Retract previous bids
- Retrieve data
- Control energy production / consumption of the facility represented by the agent
- Provide forecast of energy production / consumption represented by the agent
- Collect measurement data from the facility represented by the agent



Agents can be classified in the following categories:

- Energy consumers
- Energy producers
- Service

Each of these can then be further divided depending on, for example, whether the agent represents a passive consumer or a facility that actively control and adjust their energy consumption. Correspondingly energy producers can be active or reactive depending on whether the facility can adjust and control its production based on the market.

FED COMMUNICATION

The FED Communication provides the means for the market place to communicate with the facilities represented by the trading agents. This block includes functions to assure the authenticity of the users, limit access, store data, manage connection of devices and provide access to information to overlaying systems. An important function are the device gateways, these integrate with the underlying system, each south bound system will have their own gateway. The gateways are the single point of integration for market participants containing the support to map any number of devices and sensor in the underlying system in a consistent manner enabling that this data can be exposed in a coherent manner.

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FED VERTICALS

The FED verticals contain functionality that are shared by multiple (all or a subset) of the other functionalities provided in the market place and communication groups.

Monitoring:

- The monitoring functionality provide a simple way to keep track of the operational status, performance, and resource utilization of the machines in the solution.

Log Aggregation:

- The log aggregation functionality will collect logging information from the other functions in the solution enabling a near real-time view of the activity in the system and important assistance when troubleshooting of the solution is needed.



EXTERNALS

These are external functions that integrate with the FED System:

- Data and forecast services integration
- Facility control and measurement systems integration

The data and forecast services integrate with the market place and includes several data sources, such as weather data and energy prices. This data is needed for the trading agents to make accurate estimations and forecasts.

The facility control and measurement systems integrate with the communication and is the connection to underlying actual physical facilities such as buildings, production facilities and so on.

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4.4.3 Software Technology

In the development of the FED ICT solution Ericsson have both developed custom applications and used commercially available products as well as free open source software.

The table below shows the software used, both type and product and for what it is used.

Table 4-1 Software type and product mapped to its respective component.

Component Software type and Product mapping		
Component	COTS/FOSS/Custom	Product
Ericsson of the shelf Products		
Communication Platform	COTS	IoT Accelerator / DDM
Other of the shelf Products		
Log Aggregation	FOSS	ELK Stack [11]
Event Streaming Platform	FOSS	Apache Kafka [12]
Container Platform	FOSS	Docker [13]
Container Orchestration	FOSS	Kubernetes [14]
Market Solver	COTS	GAMS [15]
Custom Build		
Energy Market	Custom	
System Service Market	Custom	
Trading Agents	Custom	
Service Providers	Custom	
DDM Software Gateways	Custom	Based on DDM GW SDK
Runtime systems		
N/A	FOSS	Java virtual machine [16]



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4.4.4 Hardware technology

The FED ICT solution requires hardware in order to run the Market place. These are listed in the table below. It should be noted that this is in addition to the hardware required for the control and monitoring systems for the physical assets owned by the real estate owners, i.e. the SCADA and PLC systems in the buildings and production facilities.

Table 4-2 List of hardware with purpose and description.

HW BOM			
Service type	Purpose	Quantity	Description
FED Market Place (Azure)			
Virtual Machines	Container Host	3	Standard virtual machines, one D8s v3 (8 cores, 32 GB RAM) and two D4s v3 (4 cores, 16 GB RAM)
Virtual Machines	Container Manager	1	Standard virtual machine, D2s v3 (2 cores, 8 GB RAM)
Virtual Machines	Tunnel Bastion	1	Standard virtual machine, DS1 v2 (1 cores, 3.5 GB RAM)
Virtual Machines	Logs	1	Standard virtual machine, DS1 v2 (1 cores, 3.5 GB RAM)
IP Addresses	Public IP	1	classic type, 1 instance-level IP Address(es) x 744 hours, 0 load balanced IP Address(es) x 744 hours, 1 reserved IP Address(es) x 744 hours, 1 IP Address remap(s)
Azure DNS	DNS connection	1/1M	1 zone(s), 1 million queries
Real estate owners' premises			
Physical Machine	Webport - DDM Software Gateways	2	HPE ProLiant DL20 Gen9, Intel E3-1230V5, 16GB, 1TB

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5 BUSINESS MODELS

A vital aspect of creating local energy markets such as FED is to find working business models, the FED system solution must be both ecologically and economically sustainable for it to be implemented and used. In addition, there is a need to identify and find models for who should own and operate the FED system solution and who the client is. These aspects requires further study and analysis than what was included as part of the FED project.

There have been other projects studying local energy markets and potential business models, the EMPOWER project is one of these. However, the vast majority of these projects and examples focuses solely on electric energy.

This section describes potential business models for the FED system solution. These will be described on a general level, during the project these models and concepts have been validated qualitatively by industry experts. These business models reflect the identified value propositions, however, there is a need to evaluate under what conditions these models are economically viable.

The property owners highlight the possible discrepancy between environmental benefits and profitability, i.e. solutions that provide the desired environmental benefits might be too expensive. There is therefore a need for identifying incentives to the investments and actions (e.g. local generation and demand flexibility). The suggested value propositions are believed to be possible to manage within the initial market design.

5.1 Potential values and opportunities in the local energy market

The basic value with local energy markets is the possibility to trade and make use of smaller amounts of energy and flexibility than what is possible in existing markets. Also, managing more energy locally means less transmission in networks over larger distances, which over time can lead to reduced infrastructure costs.

The fundamental drivers for the local energy market in FED are:

- Local energy generation shall be free from fossil fuels.
- The use of energy from the up-stream energy system shall be reduced during peak periods when that energy causes large emissions of CO₂.
- The total amount of external energy from the up-stream energy system shall be reduced through energy recovery, energy efficiency measures and local generation.

The consequence of this is that the local energy market in FED needs to foster demand flexibility as well as local generation and storage of energy. Business models should target value propositions that address these needs.

The table below lists the identified opportunities with a brief description and which actors are involved.





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Table 5-1 Opportunities in the FED system.

Value	Description	Actors involved
Optimise energy use	High potential for energy cost savings can be achieved by having the possibility to trade multiple energy-carriers simultaneously (i.e., joint-optimization between energy systems). E.g. combinations with district heating and heat pumps. “Use of low-grade energy to replace primary energy”.	Producers, consumers, retailers
Demand response for peak load management	Possible reduction in peak demand for the system can be achieved by shifting the times of loads. The benefits can be seen as the reduction of investment costs or delayed investments to reinforce the supply grids (e.g., electrical grids). “The value of flexible kWh:s”. “Use of low-grade energy to replace primary energy”.	Producers, consumers, storage operators, flexibility providers
Demand response for enabling PV-integration	Integration of PV in the systems can lead to violation of network limits (voltage, current limits). The demand response can be activated to match with the PV production to mitigate the problems. The benefits could be seen as the reduction of cost for mitigating measures for the above problems.	Producers, consumers, DSO
Ancillary services	Reactive power from inverters of PVs or battery storage system could help to support the grid operation. The costs are increased sizes (dimension) of inverters. The benefits are the revenue from service markets as well as the reduction in cost of loss in the grid.	Producers, DSO
Scheduling for Congestion management	Local electrical network may get congested. Scheduling of production and consumption facility to avoid network congestion would improve the grid operation. The benefits are avoided congestion costs.	Producers, consumers, DSO

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Value	Description	Actors involved
Foster a sensible geographical distribution of micro-generation from a network perspective	A less geographically dense integration of micro-generation (such as PV) would be favourable in certain local grids, compared to concentrated build out in few places.	DSO, Producers
Reduce infrastructure costs	Less infrastructure when more is managed locally	Producers, consumers, DSO
Revenues from energy sales	Revenues from excess energy deliveries (electricity, heat, cold). “Use (surplus) energy later”.	Producers, consumers
Provide energy/power use forecasts	Better information on local energy flows in grids and network gives opportunities for better management of e.g. power quality and production units (heat/cold).	Producers, consumers, network operator
Energy redundancy	Local redundancy in the energy system when multiple sources can provide energy.	Producers, consumers

5.2 Needs analysis

The needs related to the FED system can be divided into two perspectives: Property owners and Utility.

5.2.1 Property owner perspective



One of the biggest challenges in the project lies in avoiding discrepancies between profitability and the environmental benefits. Though the goal of the trading system is to reduce CO₂ emissions by reducing the peak loads, from the point of view of the property owner, this must be combined with economic incentives; both criteria have to be fulfilled.

Administrative and judicial factors may on the one hand add value but also possibly limit the potential of the trading system. Should the administrative part be too extensive, and the judicial limits too strict, it could affect the profitability and outcome of the project.

Aside from the general goals, the possible benefits of the project include:

- A new type of price setting with a direct correlation to environmental aspects.
- Increased awareness about energy consumption through more precise billing.
- Stimulating energy efficiency measures to be taken dividing the cost between parties.
- Increased collaboration between the parties. This can in return lead to synergistic effects to develop.

Since the prerequisites may not be identical for different systems and campuses, it is believed that the management and structure of the trading may vary from case to case. Despite that, if the basic principles of

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the trading system presented here is applicable on campus Johanneberg, which can be seen as a society in miniature, where parties range from property owner down to an individual consumer, it should be plausible to use the same concept on other campuses and possibly even scale up and apply it on a higher level, such as a city. Though the details and workings of the trading system may vary with each trading system, the overall principles remain the same.

5.2.2 Utility perspective

Value for the stakeholders in the FED system is mainly created when they exchange temporary energy excess/needs with each other. To make it happen, a local energy market will be developed. Optimising different buildings usage profiles and adding fossil free production capacity creates an increased flexibility where price variations between heat, electricity and cooling can be exploited to reduce energy costs and environmental impacts. This flexibility can lead to reduced congestions in both heat and electricity transmissions as it increases the possibility to move loads between consumers and producers with different needs.

Another value is that the peaks of district heating production can be reduced and in the long term, savings are made possible as it reduces the need for investments in additional district heating capacity. To capture these values, Göteborg Energi needs to use an automated trading and pricing process applicable to the trading platform. Since there will be several energy producers on the Campus area the price will be set by market forces.

5.3 Value propositions



Based on the potential values and needs described above a number of value propositions have been identified. These propositions consist of components that make up building blocks for business models.

5.3.1 Local energy trading

The trading platform is used to enable local prosumer, storage operators and customers to trade excess energy with each other, sell excess energy to retailers and purchase energy from local producers. The trade is made on an energy basis, i.e. kWh of energy or storage capacity is traded. The purpose is to promote more active customers, achieve a more efficient resource use on a local level and reduce environmental impact, as well as fostering a local community for sustainable energy use.

Components:

- Environmental impact forecasts – by including primary energy factors and CO2-equivalents for each type of energy as part of the forecasts customers and producers can plan their energy use, storage and production to minimise the environmental impact.
- Peer-to-pool trading – a local pool for energy gives customers access to local micro generation in addition to major production and retailers and gives local production units or prosumers access to a market for their excess energy.
- Peer-to-peer trading – allows customers to choose selected producers of energy based on preference, e.g. distance to producer.

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5.3.2 Power services enabling aggregation of flexibility and demand response

The trading platform is used to connect flexible electricity, heat and cold customers and storage operators with utilities in order to enable demand response and aggregated flexibility to be used for peak load management. The trade is made on power basis, i.e. the trading platform enables actors to trade with kW instead of kWh. The purpose is to enable peak power reduction and shift loads in time in order to reduce production costs and environmental impact, or to avoid mitigation of renewable and variable energy sources.

Components:

- Provide more advanced power measurements and forecasts to customers – better information and transparency regarding costs related to power could enable more advanced and tailored power tariffs which can create a market for efficient user of power.
- Local power pool – a local power pool for each energy carrier including forecast can be used to reduce peak power. This requires flexible customers and that the actors can adapt and react within the required timeframe.

5.3.3 System services

The trading platform is used to trade system services from customers and prosumers. The purpose is to improve the operations grids and networks.

Components:



- Ancillary services in electric grids – reactive power, e.g. from solar PVs, could help grid operation with voltage control which can reduce losses in the distribution.
- Frequency control in electric grids
- Active filters in electric grids – filters can neutralise overtones and improve power quality
- Foster a geographically favourable distribution of micro-generation from a network perspective – for certain local grids it can be an advantage to have a more distributed generation. For instance, in outlying areas of a heating network there can be benefits with having local heat production units. Creating incentives in the FED system solution is an interesting system service.

5.4 Business model examples

During the work, two main types of business models of interest have been identified; the aggregator and the energy service company (ESCO). These are described schematically in the following sections.

5.4.1 The aggregator business model

The aggregator is an actor that can provide technical and economic services to on the one side energy customers and on the other side companies acting on the energy markets. Typically, the aggregator coordinates a large number of individual resources, e.g. the flexibility of energy customers, and packages this towards energy markets. Thus, the aggregator is a two-sided business model that serves two customer segments; energy customers and companies acting on the energy markets. Translated to the FED-project,

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aggregators could use the market platform to coordinate flexible resources in the district and provide these to the overlying energy systems, e.g. to manage peak demand.

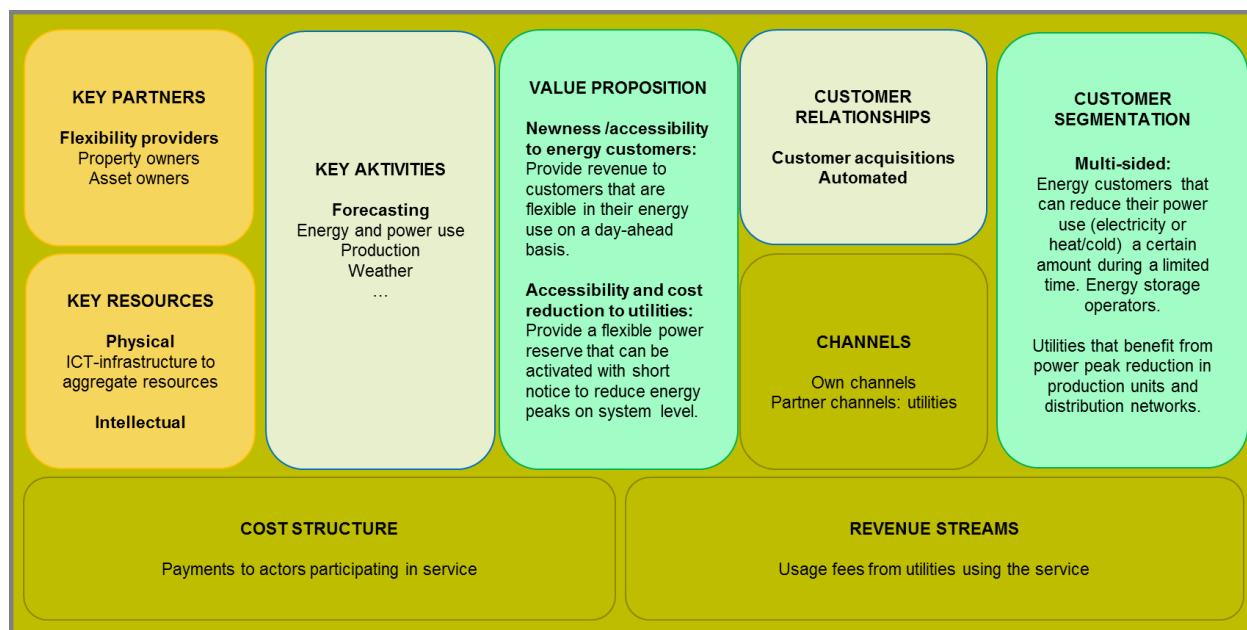




Figure 5-1 Illustration of the aggregator business model.

5.4.2 ESCO business model

The Energy Service Company (ESCO) is a company that provides energy related solutions to energy market actors and energy customers. Such solutions are e.g. energy efficiency measures, energy deliveries, forecasting etc. The ESCO could be a utility or a third party service provider on the energy market. Translated to the FED-project, ESCOs could provide optimisation of customer energy use based on advanced forecasting e.g. environmental impact. Also, system services as described in section 5.3.3 could typically be provided by an ESCO.

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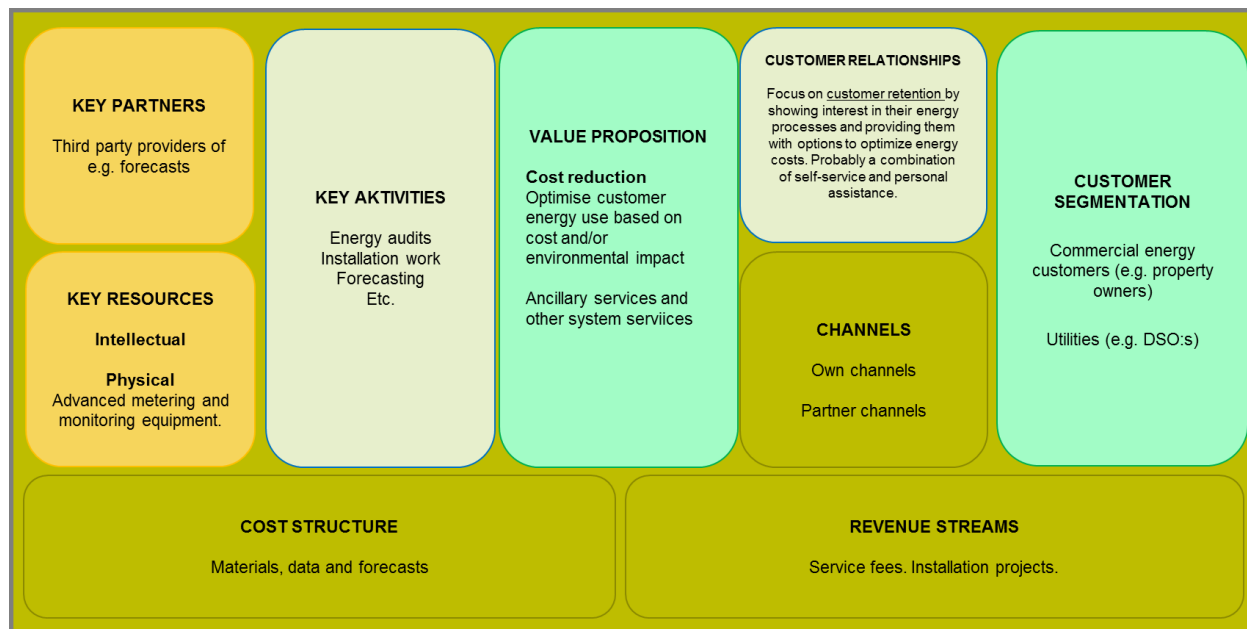


Figure 5-2 Illustration of the ESCO business model.



5.5 Further work

As stated in the beginning of this chapter finding a business model is a vital part and key success factor for implementation of solutions such as FED. The FED project did not include fully developing or proposing a business model, this work requires further study. In addition, this work is dependent on further development of the market itself. The findings from this project should serve as basis for further work and studies looking to replicate FED or similar solutions.



One aspect that has been identified in this project is the question regarding having a market operator and owner. A business model for a FED solution need to include further clarification of who should fulfil the role of market operator. This work should also include developing associated costs and revenue for this role.

Finding a fully working price model is also a field that requires further work. This includes how to set prices to reflect CO₂ emissions if one wishes to create a market that optimises the system for minimum emissions. The price model needs to balance the costs and revenue streams to ensure that the overall market is attractive for both potential market owners and market actors, including both consumers and producers as well as energy companies and distribution system owners.

An aspect that relates to the price model but also to the general design of the market is how to ensure that the market actors behave in the desired way. As discussed in this report there are risks related to strategic market behaviour but also in creating to high thresholds for entering the market. A complete business model must include mechanisms and possible safeguards to prevent dominant actors steering the market, individual actors submitting false or misleading bids and other undesirable market behaviour. But these mechanisms must be balanced against increased costs or creating an overly complicated market.

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To increase the capacity and flexibility of the FED market it is of great benefit if the business solution and model provides incentives for added investments, e.g. in local energy production or storage units. This has not been fully studied or evaluated during this project. This could also be a factor for determining the prerequisites for an area in order to be able to successfully replicate the FED solution, e.g. how much local production and flexibility capacity must already be in place and available.

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6 IMPLEMENTATION, REPLICATION AND POLICY RECOMMENDATIONS

One important aspect of the project is to look at the replicability of the FED system and what is required in order to implement a FED system solution on the energy market. This means identifying the key factors that determine whether it is possible to replicate FED and also to discuss strategies on how to handle and work to facilitate the implementation of solutions such as FED. This section will therefore describe different aspects relating to replicability including social barriers, regulatory and policy issues, an international outlook and socio-economic framework for replication.

Finally, this section will include a number of policy recommendations. These recommendations are a result of the work done in the project with regards to the identified challenges and opportunities as well as required changes to regulations in order to facilitate a replication of FED.



6.1 Strategies for social acceptance and barriers to acceptance for FED Local energy systems

The FED project is to a large extent a technical project looking at implementing technical solutions for the energy system. In such projects it is important to recognise the immense impact of social acceptance and its role in determining whether or not a FED system solution will be successful or not. If the involved actors are not willing to become part of the local energy market there will be no FED system, regardless of how well the technical side works.

This section describes an assessment of barriers and drivers for social acceptance as well as measures and strategies to facilitate this acceptance. For this assessment it is assumed that the local energy market is clearly defined and well-functioning from a technical, economic and regulatory point of view. Thereby this section focuses on the social perspective.

A marketplace that supports simultaneous trade with several energy carriers is a novel concept and previous experiences cannot be found. The identification of social drivers and barriers for local energy markets is thus based on a literature review of related fields as well as seminars and discussions on local energy markets from a broad perspective. The identified barriers for social acceptance of local energy markets are clustered into the following categories:

- Collaboration
- Community participation
- Exclusion
- Expectation
- Knowledge and information
- Path dependency

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- Policy
- Privacy
- Trust
- Values

And the identified drivers for social acceptance of local energy markets are clustered into the following categories:

- Local engagement
- Policy
- Security of supply
- Values

Note that a barrier could be the opposite to a driver and vice versa. Because of this some drivers could have been described under barriers and strategies to overcome them.

End users here refers to market actors that trade on the market. Stakeholders refer to persons, organisations, companies or systems that are affected by the local energy system. In this section stakeholders are divided by societal level. At national level this could refer to government and regulatory bodies, at regional level it could refer to energy companies, distribution system owners or municipalities. At the organisational level stakeholders could e.g. be companies providing services or real estate owners.



6.1.1 Measures to mitigate barriers

Above the identified clusters of barriers to social acceptance are listed. This section describes these barriers per cluster and some potential measures to overcome these.

Collaboration

Collaboration is a vital factor for almost every project, especially ones involving many partners or complex processes. If collaboration is ineffective, projects will be delayed or even fail to be implemented.

Barriers related to collaboration in the case of local energy markets are visualised in the figure below. To implement a local energy market, local political acceptance is crucial. In the FED context an extra layer of complexity is added by the trade with several energy carriers in one marketplace (power, heating and cooling in the case of Gothenburg). This simultaneous trade does not exist in any other markets today. The markets for different energy carriers are separated and follow different rules and regulations. To enable a novel market structure of this type, extensive collaboration and openness to different perspectives between both political actors and stakeholders on several societal levels is required.

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Political	<u>National acceptance</u>	<u>Local political acceptance</u> -Lack of cooperation between local market actors and local decision-makers.	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u> -Lack of cooperation between actors who are building and operating local infrastructure.	<u>Stakeholder acceptance</u> -Poor internal collaboration between departments handling different energy carriers.
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u>

Figure 6-1 Barriers for social acceptance related to collaboration.

Potential measures to overcome these barriers target the political and stakeholder actor groups. There is a general norm in the energy sector to avoid using electricity for heating purposes. Both policymakers and energy companies are often supporters of this concept and need information on the benefits of a flexible use and possibility to switch between different energy carriers. Further, structural changes are required for the energy system to fully support increased flexibility and switching. New business models are needed to realise this novel trade concept. Researchers within the field can contribute with facts on the benefits regarding a flexible use and a smooth switch between different energy carriers to inform policymakers and stakeholders in the energy sector.

Policymakers and political institutions should promote and enable collaborations between sectors or organisational departments handling different energy carriers, e.g. by removing any legislative or regulatory obstacles.

Further, awareness needs to be raised on the importance of collaborations within the energy sector at large. The benefits of well-functioning cooperation in e.g. energy system development, demonstration projects, large-scale implementations etc. should be communicated by, for instance, branch organisations within the energy sector.

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Community participation

The power of local engagement has been recognised in many energy-related projects and by local energy companies. Lack of true participation from the local community is here a social barrier mainly related to the lack of involvement of end users in the implementation and operation of a local energy market.

Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u> -Lack of real involvement of end users in market function and implementation.	<u>End user acceptance</u> -Lack of real and continuous involvement of end users in market development.

Figure 6-2 Barriers for social acceptance related to community participation.

A potential measure to overcome these barriers is for the local energy market operator to include end users from early stages in the market development process. This involvement must be on a reasonable level from both perspectives, taking into account the end users' interest and engagement and the market operator's willingness and abilities to share power and open up the design and operation of the market. Involvement of end users can be facilitated by an increased understanding about their needs within the market operator organisation. The market operator would therefore benefit from a continuous dialogue with end users via, for instance, focus groups or other types of meetings where end users' ideas can be discussed. Customer segmentation models could be applied to gain a better understanding for end users and their motivations to get inspiration on how to include them in the market development process.

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Exclusion

The geographical constraints of energy system infrastructure can imply that end users or stakeholders that might be interested in participating in the local trade cannot join the local market.

Actors and actor groups:	Societal level:		
	General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u> -Negative influences from those who cannot participate in the marketplace due to geographical constraints.	<u>End user acceptance</u>

Figure 6-3 Barriers for social acceptance related to exclusion.

A potential measure to overcome this barrier is to increase the understanding among the local public that the geographical constraints are not easily overcome. The market operator should therefore communicate this to the local public.

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Expectations

In general, adopters of a new technology might have unrealistic expectations of the benefits that the technology can bring, resulting in frustrations and negative feelings. This is also true for local energy markets and the end users and actors participating in the local trade.

Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u> -Unrealistic expectations from end users or stakeholders can lead to disappointments and negative attitudes.

Figure 6-4 Barriers for social acceptance related to expectations

A potential measure to overcome this barrier is for the market operator to clearly communicate the true benefits to end users and stakeholders in order to lower the risk for misinterpretations. Objective third-party actors such as experts or researchers can support this process by presenting unbiased information on the benefits and shortcomings of local energy markets.



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Knowledge and information

Barriers related to knowledge and information are mainly related to the lack of expertise, knowledge and information by actors that are not trading in the local energy market, as presented in the figure below. The successful implementation and continuous operation of a local energy market not only requires competence regarding local trade with several energy carriers as well as local market rules and regulations among the actors who could join the market, but also expertise among the actors who are not potential traders. These actors are e.g. designing or building the surrounding systems that enable a local market, such as houses or support systems and must therefore have in-depth knowledge on the requirements.

Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u> -Lack of expertise regarding local energy markets among the market actors' support functions (e.g. architects, installers, construction companies, municipal officers, etc.).	<u>Local stakeholder acceptance</u> -Lack of knowledge and competence regarding trade with several different energy carriers (stakeholders on the supply and demand side).	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u> -Lack of knowledge about local markets in general can lead to negative influences from external actors outside the local market.	<u>Local public acceptance</u> -High knowledge thresholds (regarding for instance technology, trade, interface, market procedures) that can lead to actors not joining the local market; -Lack of access to knowledge, tools or information that can prove the benefit of joining the market.	<u>End user acceptance</u>



Figure 6-5 Barriers for social acceptance related to knowledge and information.

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Potential measures to overcome these barriers are first and foremost related to information and education on the concept of local energy markets and trade with several energy carriers to increase knowledge among stakeholders and the public. The market operator should be responsible for communicating and disseminating information on the local market to lower the knowledge thresholds that might be present. A local energy school could be implemented to inform stakeholder or public groups on e.g. local trade with several energy carriers. The support functions (architects, building companies etc.) above could also be a potential target group for such a school or courses with adapted content. Demonstration projects could be a useful measure to spread information and increase knowledge.

From a broader perspective, stakeholders in the energy sector such as branch organisations and individual companies must have access to knowledge and information on local energy markets. Policymakers on all levels also require more knowledge on the concept of local energy markets and the benefits of local trade. However, the lack of knowledge and information should be investigated more in detail to enable an efficient and targeted increase in competence and know-how. An analysis of actors and knowledge gaps should therefore be conducted before any information campaigns are initiated.

As seen for other barriers and potential measures, objective experts or researchers can present impartial information on the positive and negative effects of local energy markets.

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Path dependency

The concept of path dependency comes from the research theory stating that organisations and actors are part of institutions that affects their behaviours and activities in line with established paths. These paths are made up of previous choices made in public policies and institutions. Path dependency highlights that once a path is chosen, it is difficult and costly to change it because the processes are reinforced over time. The figure below indicates that the social barriers for local energy markets that are related to path dependency are mainly present on the general level of society, in all actor groups.

Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u> -The centralized structure and organization of the energy system inhibits development towards local energy markets.	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u> -There is a norm in some countries for end users to enter into long-term energy contracts.	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u> -Current societal norms (energy as a non-issue) are hindering the development of flexible energy systems and local energy markets; -Changes in consumption patterns are highly problematic for most users (both for end users/households and for commercial firms).	<u>Local public acceptance</u>	<u>End user acceptance</u>

Figure 6-6 Barriers for social acceptance related to path dependency.

Potential measures to overcome these barriers are naturally targeting current institutional structures on national and EU level. If local energy markets are to be implemented there is a need for change in the current structures of the energy systems and to initiate actions that affects institutions and other actor groups in the social system. For this to be realised political decision-makers and governmental agencies must realise and understand this need and potential benefits. Best practice examples from successful energy system developments should be communicated, especially regarding local energy markets. When more countries and cities have implemented local markets, success stories from the places that benefit the most from local energy trade should be communicated.

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Governmental agencies and branch organisations within the energy sector should take action to increase the public interest for energy and knowledge regarding the benefits of changed consumption patterns, e.g. through innovative communication to gain attention. Incentives (not only economic) can also be applied to stimulate change but must be carefully designed.

End users can be stimulated by realizing the personal benefits that can come from a change in current systems. These benefits might be economic but could also be environmental, social or other. Tools to present such personal benefits in a comprehensive manner should therefore be developed by market operators.



Policy

Policy on a national or EU level will have an impact on the development of local energy markets. As apparent in the figure below, the barriers are quite well-defined and isolated in the social context, related to political goals, ambitions and actions. The concept of local energy markets for trade with several energy carriers is a rather novel concept and requires political will and initiatives to be realized. The effects of policymaking will naturally have effects on all other levels and target groups.

Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u> -There is a strong political will (mainly on EU level) towards a harmonized single market for energy (both regarding infrastructure and legislation); -Ambiguity and lack of long term stability in policymaking and political goal-setting; -Lack of politically initiated institutional changes.	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u>

Figure 6-7 Barriers for social acceptance related to policy

Potential measures to overcome these barriers are for policymakers and political decision makers on EU and national levels to agree on long-term solutions that stimulate the development of local energy markets.

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Visions and strategies for the whole energy system and the different energy markets are needed on EU and national levels, taking into consideration the integration of different energy carriers. Further, there should be a strong and clear political leadership. Political goals for local energy markets and the energy system must be clarified and institutional changes initiated in time.

Researchers, experts and companies or branch organisations within the energy sector can support policymakers and political decision makers by describing and communicating the benefits of local markets regarding for instance environmental gains. Demonstration projects can be a powerful measure in this regard.

Privacy

Privacy concerning end user energy data is a bigger issue in some parts of Europe than other. As abundance of energy data is growing, this barrier needs to be properly addressed.



Actors and actor groups:	Societal level:		
	General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u> -Unwillingness to publish projections that reveal the organisation's operations during the coming days.	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u> -Handling and ownership of production and consumption data is unclear.

Figure 6-8 Barriers for social acceptance related to privacy.

Potential measures to overcome these barriers are for the market operator to be clear and transparent regarding data handling procedures in the market. The market operator will not only follow existing data legislation but should also communicate this to end users. Also, a strategy for handling data projections without revealing future organisational operations should be developed.

Trust

Trust is vital when it comes to implementation and change processes. If the actors in the local market don't trust the market operator, the underlying technology, the market model or each other, they aren't very



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likely to participate in the trade. It has been noted that external actors who are originally not part of the local community often struggle more with trust issues than local actors trying to implement a new technical solution.

Actors and actor groups:	Societal level:		
	General (national at minimum)	Local/Community (region or municipality)	Household/organisation/end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u> -Lack of political trust, transparency and feedback to gain consumer involvement and acceptance.	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u> -Lack of trust in the actors responsible for the operation of the local market.	<u>Stakeholder acceptance</u> -Lack of confidence in local markets and the technology solution from the stakeholders influencing the market; -Low level of trust between actors and institutions and between different actors.
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u> -Lack of confidence to the local market business model and the technical system behind the market from end users; - Poor communication and management of risks.

Figure 6-9 Barriers for social acceptance related to trust.

Potential measures to overcome these barriers are to establish solid long-term relations, primarily between the market operator, stakeholders and end users. Such relationships need to be built over time and could be supported by continuous communication and transparency regarding the local market, business models and market procedures. Additional trust from end users can be gained by opening up the local market to some degree of end user participation. Co-ownership models for the local energy market can increase the trust and acceptance from end users and stakeholders.



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To establish trust in the technical solution, the market operator could demonstrate the technology and provide proof for its smooth and safe operation. The market operator's actions will also be important during the continuous operation of the local market as they must prove to be capable of handling and mitigating risks and problems. Well-functioning and continuous customer support will increase the trust from end users.

For market operators who are not part of the local community and tries to implement a local energy market as an external actor, it would be beneficial to make alliances with local stakeholders who are trusted by end users and stakeholders within the community. A license for market operation issued by an objective third party can reassure end users as well as stakeholders and build trust towards the market operator. Last but not least, policymaking on all levels should be long-term, stable and clear regarding the development of local energy markets.

Values

Individual citizens' actions and engagements are often determined by personal values. By not considering such values in the development and implementation of a local energy market, public acceptance might be affected negatively. Values that can act as social barriers to local energy markets if not taken into account by the market operator are the relation to the local context and the need for social comparisons among neighbours and peers as presented in the figure below.



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Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u> - Political beliefs.
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u> - Lack of identity factors such as cultural heritage, emotional and cultural connections to a place, or involvement of actors that are important for community identity; -Visibility and lack of image factor. The “invisible” trading on a local market doesn’t enable peer comparison.	<u>End user acceptance</u>

Figure 6-10 Barriers for social acceptance related to values.

Potential measures to overcome these barriers are for market operators to take the local context into consideration from early stages of the planning and development process; both in the design, implementation and operation of the local energy market. Local ambassadors and role models can inspire others to join the market by communicating their participation in the local energy market, e.g. via social media. Market operators should thus engage such ambassadors and enable a wide-spread communication. Initiating collaboration between the market operator and local stakeholders significant for the community is another way to overcome this value-related barrier. Further, the share of locally produced and traded energy should be clearly communicated to address local benefits.

Enabling communication is also the key to mitigate the barrier of lacking visibility. Market operators should therefore provide tools and facts that supports public display of participation in local trade and as well as the resulting benefits. This could for instance be communicated in social media or physically on screens or similar. Thus, comprehensive social comparisons between end uses and stakeholders are enabled but not mandatory. To stimulate these values on a larger societal level, contests between different cities with local energy markets could be initiated to compare the share of local trade and the benefits from this trade.

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The barrier posed by political values could be addressed by emphasizing the personal benefits from participating in the local energy market. This should be communicated by the market operator, branch organisations within the energy sector as well as policymakers on national and local levels.

6.1.2 Strategies to stimulate drivers

The clusters of identified drivers for social acceptance were listed above. Below these are described in more detail together with potential measures to stimulate them.

Local engagement

Local engagement can become a key to success in many areas and also when it comes to local or regional energy markets. Committed individuals that become early adopters and propagate their opinion on the market are a strong driver provided a positive experience. With a number of engaged participants and representatives, it opens up for a possibility to create a special community feeling around the local market. If this local engagement should be promoted by the operator of the market, as well as the local community, it can become a driving force for local engagement. Local engagement can also be created on a local institutional level between actors working to serve and promote the region. Local economic benefits from the market that creates real value for the local community will stimulate to a wider range of social benefits in the region, e.g. by support to voluntary work, sport clubs, local schools etc. On the national level the direct impact might be less obvious, but an engaged local market could act as a role model and a show case to policy decision makers on different societal levels.

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Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u> -Committed individuals and supportive local institutions; -Participatory decision-making and co-ownership in the local market; -Retained economic benefits in the community.	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u> -Local community feeling within the market.	<u>End user acceptance</u>

Figure 6-11 Identified drivers to social acceptance related to local engagement.

Potential measures to stimulate these drivers are mainly targeting the market operator. By creating new arenas with relevant activities for users, potential users and stakeholders outside the market, the operator of the market and/or the local community, can boost the local engagement in different ways. This could e.g. be places to meet other users to discuss, local events to attend to seek new knowledge etc. This could be done physically or in digital forums or social media. Another way is to engage local ambassadors to become spokespersons for the market in the community. This could be done with local celebrities, which tend to be perceived like marketing campaigns by the users. Another setup could be to engage regular users as neighbourhood ambassadors. This can be perceived as a more confident and “down to earth” way to engage the user groups, rather than using celebrities.

The local engagement can also be influenced by the legal structure of the market. The possibilities for local participation by the users in the development of the market, or even local user co-ownership in the market, tend to have a positive effect on the engagement. In situations where co-ownership for the market actors is not an option, the market operator can find strategies with tools and forums for user involvement that also can be used to boost local engagement.

Promoting success stories with benefits from local engagement from other regions or other parallel markets as well as setting up local user clubs with economic kick-back solutions (bonus systems) are other



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examples of activities to promote local engagement. Note that a positive local engagement can only be created if there are real end user benefit and local community benefit from the local energy market. Otherwise the local engagement can be just as strong, but in a negative direction, and then become a barrier for further development.

Policy

National policy's is one of the main drivers for activities on the energy market and plays a major role as a social (and economic) driver for a regional energy market. From the perspective of the FED project, European and regional policy's also has an impact as social drivers for a regional energy market. From a high level perspective the policymaking are influenced by two main areas, securing a reliable and affordable national and European energy supply and adapting to counteract the negative climate change. Fossil free and renewable regional energy markets could address both these strategic areas of interest.

One observation is the trend enabled by new technologies with local wind, solar and bio energy production that has initiated a system change from a serial energy system with large production plants and traditional consumers to a more distributed power system with prosumers (end users becoming both producers and consumers). Besides the economic drivers created with taxes and subsidies, the policy impact from a united and long term energy strategy promoting the benefits for consumers, driving rural development, and promoting regional and local initiatives to secure energy supply, is an mayor driver on all three policy levels.



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Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u> -Political stimulations for local energy markets on national or EU level; -Political engagement in consumer empowerment and benefit; -Trends are favouring decentralised energy systems and generation (even though the institutions are still highly centralised); -Local energy systems can potentially contribute to the overall energy and climate objectives, helping reverse energy consumption and emissions trends worldwide.	<u>Local political acceptance</u> -Political engagement in rural development; -Minimize regional CO ₂ emission.	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u>

Figure 6-12 Identified drivers to social acceptance related to policy.

Potential strategies to stimulate these drivers are for instance related to policymakers. From a policymaker perspective it is important to evaluate the impact and effect of a regional energy market to validate the effects of existing policy's as a baseline for coming strategies and regulations. Cost benefit analysis from a societal perspective can, if there are clear benefits, be used to provide important facts and figures to use as a baseline for new strategies and policy's, affecting the social drivers. From the European perspective it is also valuable to understand if the benefits of regional energy markets like FED are related to a geographical context. Are there geographic areas that benefit more from a regional market e.g. to fight energy poverty or to increase availability of energy distribution?

Proof for clear social (and economic) benefits is a very good baseline for influencing policymakers in all levels, but also to boost the public interest for a new market model such as FED. Engagement from local

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policymakers can have a positive impact on the regional energy market development in relation to city planning, smart city development plans, and local community transportation infrastructure etc.



Security of supply

Acceptances of energy delivery failures are decreasing over time among professional energy consumers as well as household consumers. Our homes become more and more dependent on reliable energy supply, not only for heating, but also for keeping security-, communication- and smart home systems up and running. There are regions that are more vulnerable to energy disruptions than others. Some reasons for this is e.g. that they are geographically remote locations and/or that there are energy infrastructure or production shortages in the region. The public opinion for, and engagement in, a local energy market tends to be higher in these regions.

Actors and actor groups:	Societal level:		
	General (national at minimum)	Local/Community (region or municipality)	Household/organisation/end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u>	<u>User acceptance</u>
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u> -A more secure and stable access to energy through local trade.	<u>Stakeholder acceptance</u> -Customer demands are increasingly important due to energy dependency.
Public	<u>Public acceptance</u>	<u>Local public acceptance</u>	<u>End user acceptance</u>

Figure 6-13 Identified drivers to social acceptance related to security of supply.

Potential strategies to stimulate these drivers relate to the trust in the market and the possibility to increase the quality on the energy deliveries. An energy market where local actors can support each other by trading on the energy surplus is less vulnerable and not so dependent on the surrounding infrastructure. This however requires a higher reliability in the energy systems with a regional energy market than without. Proof of concept is critical for the security of supply driver.



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Values

Norms and values have an impact on social acceptance, both on a personal level but also on a societal level. They can vary from one end of the scale where users strive to become totally independent from energy suppliers and want to cut the cables and pipes to the energy supplier, to the other end of the scale with users that totally rely on their energy supplier without questioning anything. And there are the full scale of user's in-between these extremes.

A stakeholder with strong engagement and values for the environment is more likely to promote a solution based on fossil free, CO₂ neutral, renewable energy in the same way as a stakeholder with strong engagement for the development of the local community have a shorter way to adapt the concept of a local energy market than others. Both users will also have a lower threshold for acceptance and a higher will to pay than the average stakeholder. Finding ways to promote these types of stakeholder values can generate very good ambassadors for a regional market solution.



Political values are also important drivers (as well as it could be a barrier) for a market based energy system. The concept with a free market in opposite to a regulated national supplier is a key divide between opposite political ideology's meaning there are political advocates for both sides.

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Actors and actor groups:	Societal level: General (national at minimum)	Local/Community (region or municipality)	Household/ organisation/ end user
Political	<u>National acceptance</u>	<u>Local political acceptance</u> - Energy autonomy and self-sufficiency, more reliability, alternative competitive energy supply.	<u>User acceptance</u> -Political beliefs.
Stakeholder	<u>Stakeholder acceptance</u>	<u>Local stakeholder acceptance</u>	<u>Stakeholder acceptance</u>
Public	<u>Public acceptance</u> -Independence from traditional utilities; -Higher willingness to pay for local energy; -Active engagement towards renewables and energy savings; -Environmental concerns.	<u>Local public acceptance</u> -Trend towards locally produced resources; -Contributing to the local community, social responsibility.	<u>End user acceptance</u> -Concerns for health, everyday life and the local context. Thus, energy use and the benefits of a local market can be related to these elements; -Concerns of what peers think. This enables peer pressure and comparisons, for instance via social media or discussions.

Figure 6-14 Identified drivers to social acceptance related to values.

Potential strategies to stimulate these drivers are influenced by information and knowledge. A strategy with a message to the market based on facts and figures for the local benefits, as well as the user benefits, is one of the most important tools to influence the different stakeholders. A key benefit for a local energy market with energy producing customers (prosumers) could be the transformation from fossil fuels for cars over to electric energy. The possibility to be self-sufficient on fuel will create new market opportunities for local renewable energy production. An example is to bundle offerings from the local energy market with e.g. solar energy production kits for home use, battery home energy storage solutions or with electric vehicles like cars or electric bikes. These kinds of activities are to a large share economic driver but they are also affecting the social acceptance for the local market as a whole.

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Making sure all the energy delivered from the market is marked with its origin (produced inside or outside the market) is also one way of promoting the local value. Another could be to make sure there are tools to compare and display benefits of the local market for those that have entered the market, compared to those that haven't. Benefits can be displayed in different ways and one way of getting the message through is to focus on comparisons or similes. One simile could e.g. be to display the amount of fossil energy cut down in the whole region after the introduction of the FED market. This can be communicated in environmental gain for the neighborhood or even in effects on the health for the people in the regional area. This is much easier to relate to for the end users than saved kWh or saved kg CO₂.



6.1.3 Conclusions and recommendations

Even though context-dependent, it is apparent from the research that social acceptance issues are of major importance for technology implementations, such as local energy markets. The social aspects need to be lifted and captured by the actors responsible for project implementation and design in the early stages of development. However, the assumptions made in this report must first be fulfilled: the technical, economic, regulatory and market design aspects must be in place and well-functioning.

To increase the chances of a successful implementation of technologies such as local energy markets, social aspects should be investigated in depth. A strategy for considering social aspects in technology implementation could provide support. The energy sector must in such a strategy ask relevant questions beyond technology to understand the end users. Why would these actors decide to participate in the local energy market? Under which conditions are they willing to invest in their own local production capacity, and how? Under which conditions are they willing to accept local market rules and procedures? Are they willing and able to change their electricity consumption practices? The most important question to ask is under what conditions such willingness can be promoted and increased, and to design the project implementation accordingly.

Finally, a list of recommendations regarding aspects to consider for different actors is presented. These recommendations support the emergence of local energy markets by addressing factors that could be affecting social acceptance. **Market operators** are for instance recommended to involve the local community, show capability, openness and transparency as well as apply tools and methods to influence social acceptance. **Policymakers** are recommended to support the transition to local energy markets through long-term and clear policymaking. Recommendations for the **local community** put an emphasis on the importance of enabling collaboration and promoting local benefits. **Researchers and objective experts** are recommended to contribute with knowledge and information to energy system development.

Recommendations for **the FED project** are, among others, to provide proof of concept for the local energy market solution and to develop guarantees of origin for locally produced energy. Further, social acceptance should be taken into consideration in case of market expansion, replication and future development projects. The feasibility of replicating the FED solution in other cities is both depending on the existing energy infrastructures and on the political, regulatory and societal landscapes. Finding cities with a sustainable city profile and engaged actors will increase the possibility for successful replication.



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6.2 Socio-economic framework

This section provides a qualitative assessment of the socio-economic effects of implementing a local energy market that includes three energy carriers. In this work the market actors and their relations are mapped and the impact are analysed.

6.2.1 Roles and actors in current energy markets

To understand the impact of implementing a local energy market it is helpful to look at and identify the roles and actors on the energy market as it typically looks today. An actor can take on several roles, such as local energy producer and storage operator. Similarly, some roles cannot be handled by a single actor, e.g. the DSOs in Sweden are not allowed to produce electricity due to regulation. The figure below illustrates the roles and actors on today's energy market.

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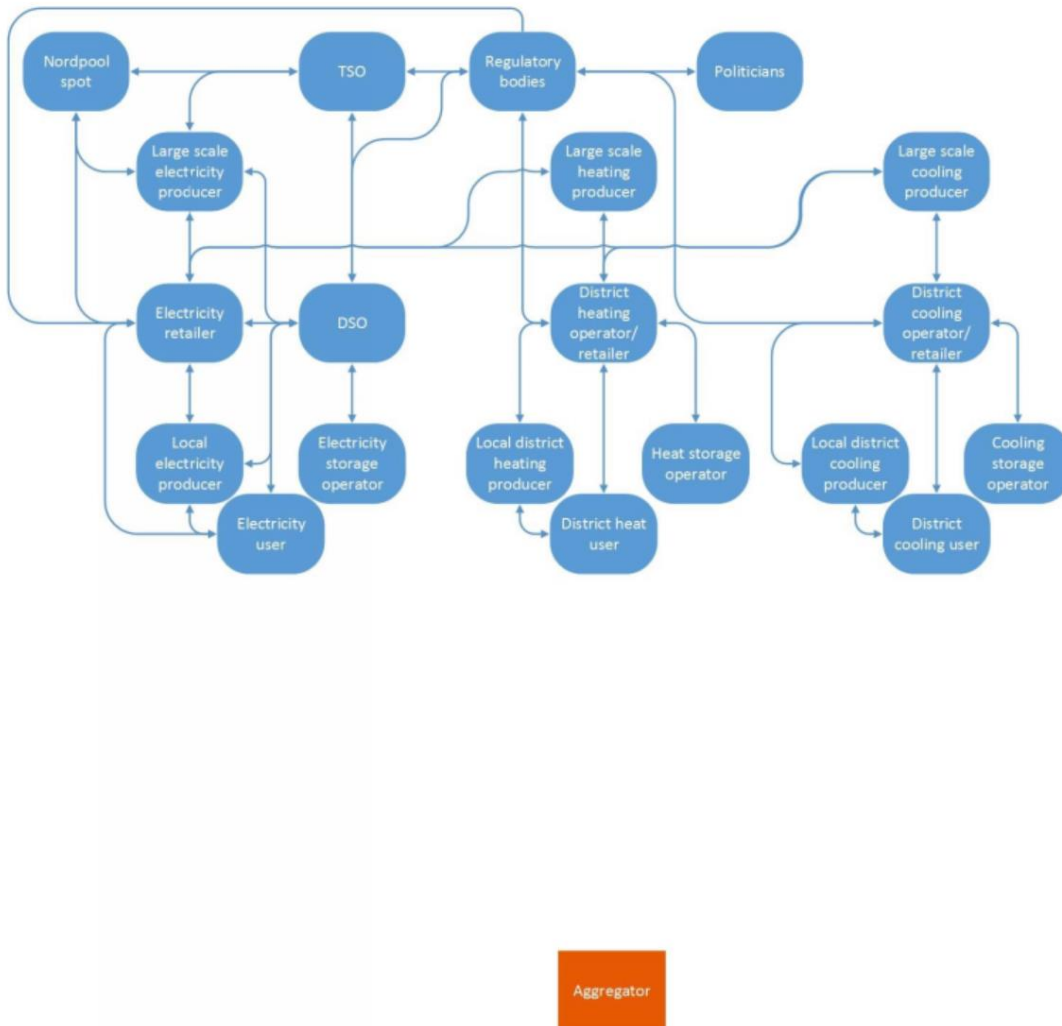




Figure 6-15 Actors and roles on today's energy market

From this the direct and indirect stakeholders can be identified. Direct stakeholders include:

- Local energy producers
- Energy users
- Storage operators
- System operators

Local energy producers are, as the name suggests, producers of electricity, heating or cooling within the system. They can be an actor that only produces energy but could also be combined with other roles, e.g. a building with solar PVs.

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Storage operators can also be either independent actors that only include an energy storage or as part of an other role, typically a building that includes a storage capacity (e.g. battery storage or thermal storage using the thermal mass of the building structure). Depending on whether the actor is solely a storage operator or as a part of a building the objective and operation may vary.

System operators include the electric distribution system operator, the district heating system operator and the district cooling system operator. These can typically be combined with the role of energy producers for district heating and cooling. One issue for system operators with regards to local energy markets is when the cost of local energy production is reduced and the energy user decides to generate their energy locally. In this scenario, the income of the DSO will be affected, and this will require a new business model for the DSO in the future.

Indirect stakeholders:

- Large scale energy producers
- Electricity retailer
- Nord Pool Spot (or other spot market operator)
- Transmission System Operator (TSO)
- Regulatory Bodies

The large-scale energy producers is an actor that mainly provide energy to the customers, for district heating and cooling this role are generally taken by the system operator.


Nord Pool Spot is a power market where the majority of the electricity for the Nordic countries is traded. This has a relation with the retailers and large electricity producers to allow them to participate in the market.

The Transmission System Operator is responsible for the operation of the electrical national network for electricity and shall ensure the security of supply and balance in the overall system.

Regulatory bodies provide and develop regulations that the actors on a local energy market need to comply with. This is also related to the political establishment. In order to be able to implement local energy market they either have to comply with the current legislation and regulations or work together with the regulatory bodies to develop new regulations that allow for such local markets. This is therefore an important role and actor.

6.2.2 Roles and actors in FED scenario

With a proposed FED system in place the relations and roles presented in the previous section will be changed. This is illustrated in the figure below.

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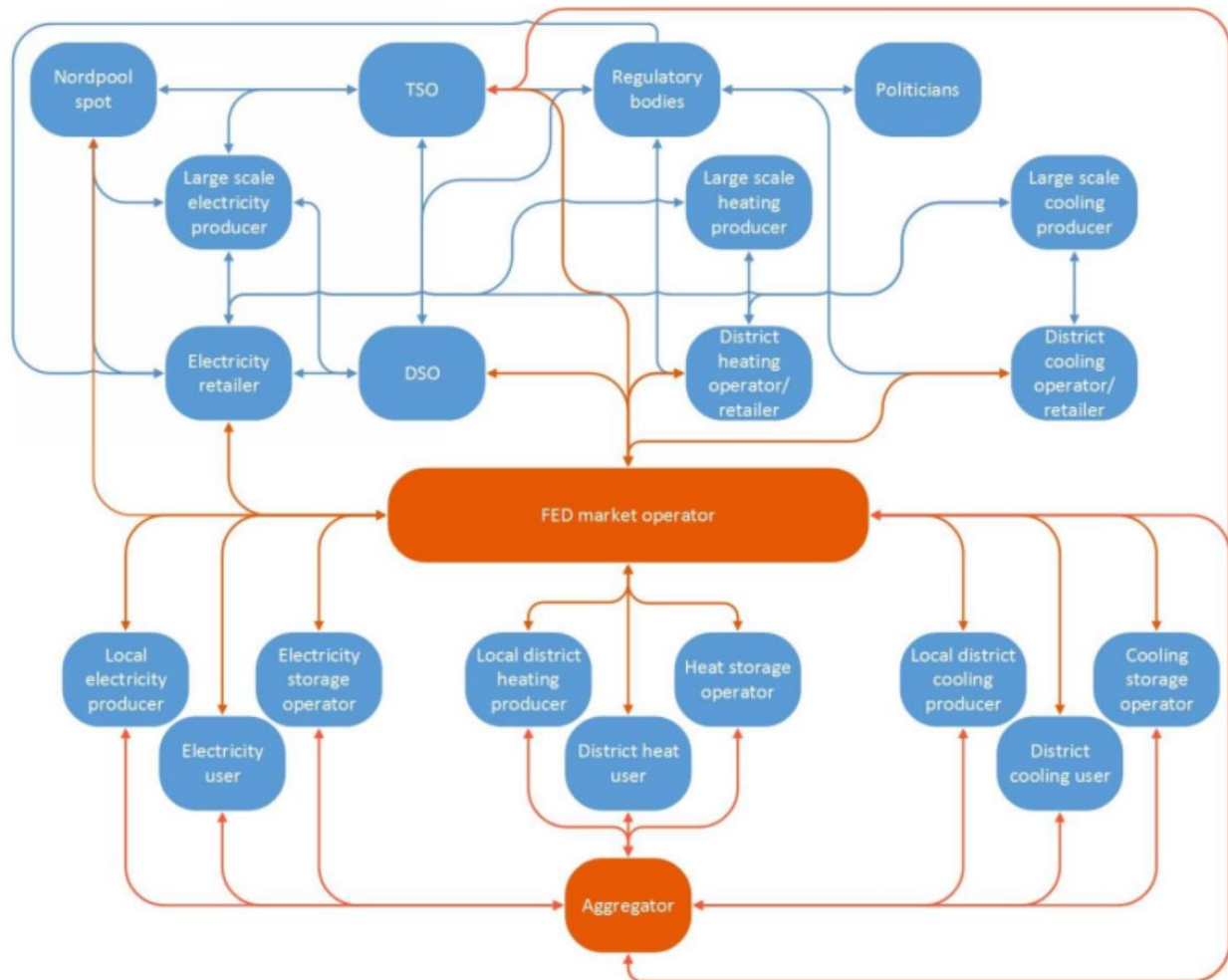




Figure 6-16 Actors and roles in the FED system.

In this figure only the roles and relations that have changed compared with the current energy market are presented. It should be noted that the participation in the FED system is voluntary and the actor can choose to keep their old relations if desired.

Local energy producers

The local energy producers will trade their energy through the FED market platform. But their participation in the market could also be handled through an aggregator. The participation could ease the dispatch for producers that take on several roles e.g. both electricity and heat producer due to the simultaneous clearing of the markets.

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Aggregator

The role of an aggregator in the FED market will be the one who represents small end-customers or small producers to buy or sell energy on the FED market. The aggregator can assume the functions to make the schedule of consumption of energy for end-users or schedule for production of small producers. The aggregator's objective is to maximize its profits from trading in FED market.

Energy users

Similar to the energy producers, the energy users will purchase their energy via the FED market, either directly or via an aggregator. For energy users with flexibility in their energy demand, the local energy market may provide incentives for these customers to utilize the flexibility.

Storage operator

A key feature of the FED market is to allow for flexibility bids. This will enable storage operators to participate in the market and to utilize the storage capacity when it is most valuable from a market perspective.

System operator

The FED market enables the possibility for the system operators to purchase system services locally. With the direct connection between the different energy carriers, flexibilities in e.g. the heat system could be used to allow for a more economically provision of system services.

Electricity retailer



The electricity retailer can trade electricity via the FED market instead of selling/buying directly to/from the electricity user or producer. Electricity retailer can also be the bridge to connect FED market and Nord Pool spot, i.e. electricity wholesale market. This bridge serves as a sort of “energy balancing” when there is deficit or surplus of energy within FED.

TSO

The TSO will be connected to the FED market and could purchase system services or flexibility from the local energy system at the same time as it complies with restrictions in the local distribution system. With the direct connection between the different energy carriers, flexibilities in e.g. the heat system could be used to allow for a more economically provision of system services for the TSO

6.2.3 Impact assessment

Generally, the actors that will be affected most by the implementation of a local energy market – a FED-system - are most likely the district heating and cooling companies and end-users. Most actors that are already present in the electricity market will not be affected to the same extent due to the extensive regulation on electricity networks that is more or less harmonized within the EU. Electricity trading actors will, however, be affected by the introduction of a local market and will thereby be able to provide new services.

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The district heating sector is facing challenges that are important to consider when assessing the introduction of local energy markets. Some of the challenges that the industry stands before are reduced demand for heat due to energy efficiency, competition from more efficient heat pumps and the fact that it is hard to find new profitable markets for district heating. There are also changed customer requirements such as increased influence on heating costs and demands for district heating with low-carbon and environmental conditions.

The district heating companies also experience rules for pricing and third party access for residual heat suppliers as well as instruments and EU directives. The cost structure is large fixed costs, large reinvestment needs, rising fuel prices and high yield requirements from the owners. District heating offers good opportunities to become an integral part of the sustainable energy system and contribute to social goals such as low emissions from heat recovery, reduced use of primary energy and synergies with other sectors, such as the electricity market and energy recovery.



Regarding end user's acceptance on a local energy market, it is important to consider the information that end users get access to and how. The information should be correct and well-communicated in order to provide good conditions for end users to be active on the new market. The term 'activity' can be expressed as the replacement of an energy supplier, but may, for example, also mean that the end users address complaints against electricity dealers and electricity grid companies in case of dissatisfaction. End users can influence market players and contribute to enhanced competition in the energy market.

Flexibility providers are likely to benefit from the FED market, the ability to change or move energy consumption based on price will be more important and in demand in future energy systems with a higher share of volatile, renewable energy production. However, flexibility will come with a cost for the provider to invest in technology and for additional ICT, this must be offset by possibilities for revenue for the provider. System benefits for flexibility is more efficient utilisation of resources and lower climate impact with potential for lower total system costs.

For DSO a FED market can provide benefits in reliability, better use of renewable resources, reduced costs for reinforcements and losses in the distribution system. But there are challenges in how to handle increasing shares of heat pumps, electric vehicles, solar PV panels as well as reduced revenue due to lower energy purchases. Costs for ICT solutions, customer support and services will also increase and need to be addressed.

The unique aspect of FED to integrate several energy carriers is expected to provide benefits to the overall system in terms of increased efficiency and optimised use of resources. The integration of electricity with heating and cooling can contribute to load equalisation and to minimise the environmental impact of the energy production. The FED system provides incentives for the actors to switch between energy carriers to avoid peak loads and using energy that is produced with fossil fuel.

There are some challenges connected to integrating and allowing for switching between energy carriers, e.g. regulations, legislation, finding forms for co-operation and communication between sectors and also technical barriers. One example of a technical barrier is that heat pumps are built for continuous operation and not short start and stop cycles that might be requested in a FED type solution. Another technical challenge is the ICT infrastructure and solution, both on the real estate owner side (measurement and communication) and the requirements for the trading platform itself (required investments, cyber security and how to operate it).

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Benefits and costs for the key stakeholders in FED are summarised in the figure below.

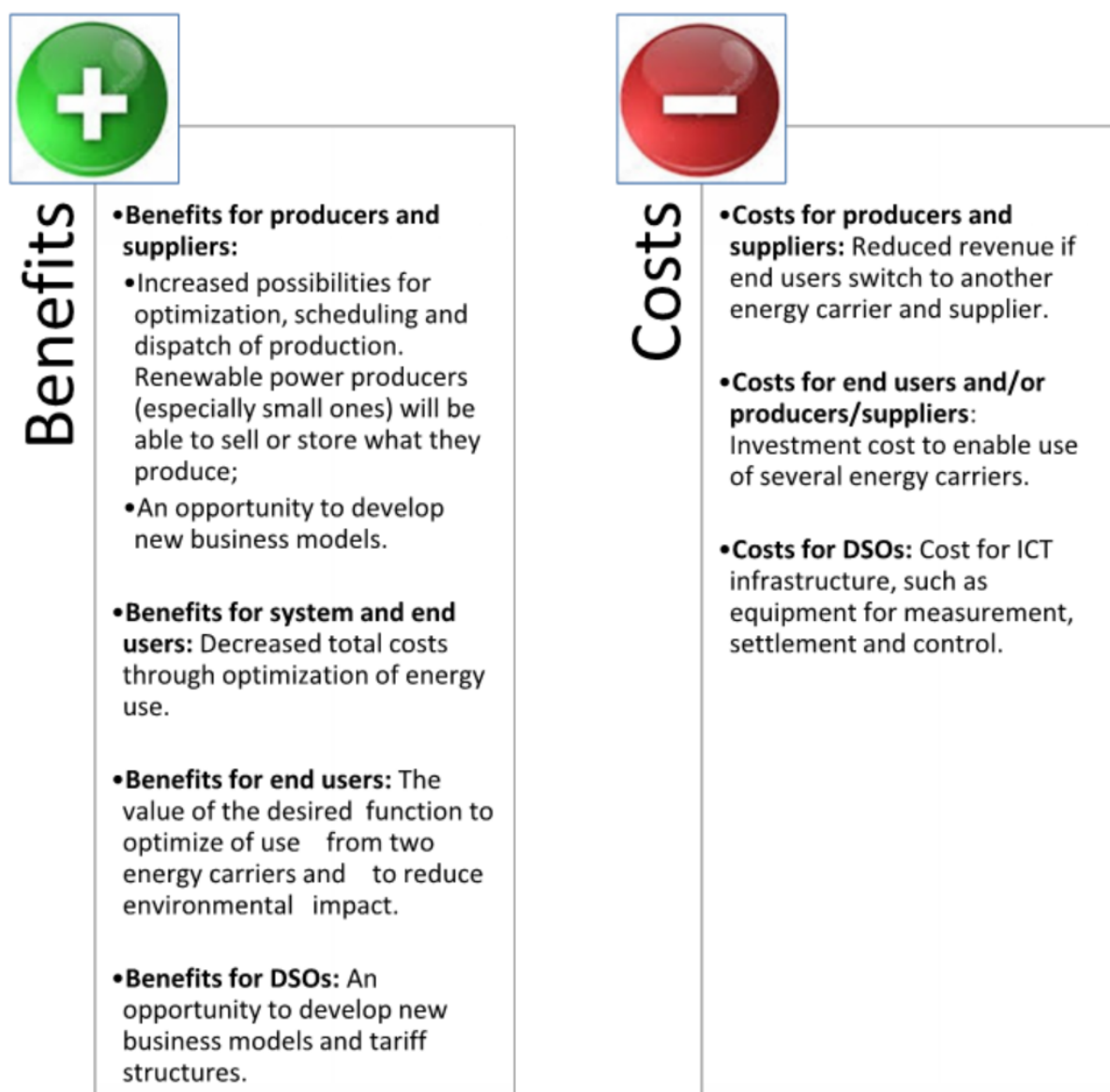




Figure 6-17 Main costs and benefits for key stakeholders.

6.2.4 European scenario

The European energy market differs from the Swedish and a part of the FED project has been to study the main differences and how these relate to a future replication of FED in another country.

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One of the main differences is related to the available energy infrastructure. There are few places in Europe that could implement a FED system as it is designed in the Swedish context, integrating the grids for electricity, district heating and cooling. In Europe, heating and cooling are not used as energy carriers to a large extent. They are rather products from electricity and natural gas, and large investments in district heating and cooling infrastructure would be needed to change this situation. Considering the extent of the investments needed for renewable electricity generation and expansion of power grids in coming years, it is not considered to be likely that the EU will prioritize large investments in district heating or cooling networks soon.



A FED system in Europe would rather integrate networks for natural gas and electricity, as these are the dominating energy carriers in that context. The FED market and trading platform are designed to be independent of the type of energy traded. This implies that the FED system could be replicated to other energy systems regardless of what energy carriers it contains.

Natural gas holds a relatively strong position as a fuel for energy production in the EU and the implementation of a local energy market for electricity and gas could increase the possibility to switch natural gas for other energy carriers, thus decreasing the climate impact. Implementing a FED system for electricity and gas networks in a European context would certainly affect the value chain for natural gas, particularly the suppliers. The effects on actors in the natural gas market would be larger in the European scenario than in the business-as-usual (BAU) scenario since gas is used to a very small extent for energy production in the Swedish context. The fact that the energy production mix differs between Sweden and EU (there is more fossil-based energy production in the EU than on a Swedish level) will probably imply that the countries that lack a low-carbon energy production will be acting as strong driving forces for an increased share of renewables.

There are various European cities that could implement the FED system for electricity and district heating grids, perhaps even cooling. In these cities, the production mix would still be more fossil-based than in Sweden and the FED system could make climate impact through enabling a switch between energy carriers. The replication of a FED market to these cities would probably be hindered by country-specific contextual factors such as regulations and institutions rather than the structure of the individual markets for electricity, heating and cooling.

The fulfilment of the FED goals at the Swedish demonstration site at Chalmers Campus is depending on the input of biomass. Bio-based material within EU is mainly used as biofuels for transport. The Renewable Energy Directive points out that member states should create national policies to develop existing biomass resources and mobilise new biomass resources for different uses. However, there are on-going discussions on cultivation of biomass for energy purposes compared to land use for food crops. It is not considered likely that the EU will reach the high level of biomass use for energy production as Sweden (where biomass for electricity production and heat is cheap and abundant), but rather continue to be depending on natural gas. This implies that the concept of a FED system fulfilling the FED goals would be even harder to accomplish in EU than in the Swedish context as the energy systems to be integrated would be depending on fossil fuels.

Finally, the implementation of a FED system in the EU might provide great benefits to the power grids, especially in regions with weak power grids as the FED system will decrease the load on the grid through local balancing of supply and demand.

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6.3 Legislation and governance - Opportunities and Strategies for replication

This section describes the opportunities and challenges connected to the replication of the FED system, it specifically looks at this from a legislative and regulatory angle. In addition, this chapter include a strategy for how to work in order to facilitate a replication.

6.3.1 Opportunities

One of the tools to conduct an energy transition within EU to reach fossil free, secure supply of energy, smart system solutions and long-term sustainable business models, is the FED solution, seen from a city perspective.

Gothenburg aims at becoming a fossil-free city where FED can be one of the tools to reach the goal. Gothenburg also has a future power demand which is a driving force for projects similar to FED.

FED is a powerful tool with an innovative local market place. FED automates the trade of energy carriers through IoT and enables efficient control of electricity, heating and cooling, taking care of the energy, avoiding fossil peaks in the grids together with optimized use of energy storage. In total available resources are utilized better. FED is also a project strengthening the brands of stakeholders together with the city of Gothenburg.

No special permits are required from authorities to own or trade in a local trading place for energy. However, generally speaking, within the EU, current regulations and legislation are not adapted to today's need for distributed energy solutions and a greater proportion of renewable power generation in the power system.

Current regulations on electricity markets in the EU need to change in order to create flexibility in a local energy market, which in turn benefits the players. Incentives similar to what is available in Sweden, may also need to be introduced in other EU countries.



Regulations that are barriers to a local energy market are:

- The Electricity Act
- The Unbundling Act
- Third Party Access (TPA)

The Electricity Act does not allow the transport of electricity by other operators than DSO within a limited area. The Unbundling Act does not allow the same legal person to sell services both in power grids, electricity trading and production. The law in regard to Third Party Access (TPA) is not a legal barrier per se, but in reality a technical and economic barrier depending on the technical requirements from the utility.

The clean energy proposal from the EU on local energy communities can provide better conditions. There are suggestions that DSO will have an expanded role enabling the purchase of system services that could be offered at a local marketplace by a local system operator or an aggregator.

The EU strategy for heating and cooling includes plans to make energy efficient renovations to buildings, develop energy efficiency guidelines for public schools, hospitals and improve the reliability of energy performance for buildings.

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The strategy also aims to better integrate the electricity system with district heating and cooling systems. Systems for district heating and cooling can be powered by stored electricity and heat from renewable sources and then distributed to buildings and industrial areas, increasing the level of renewable heating and cooling.

Another part of the EU strategy is to use energy waste from industry. Enough heat leaks into the air and water from industry to meet the EU's entire heating demand in the housing and services industry. One way to address this problem is to link the industry with district heating systems – a practice already in place in Gothenburg, where 90% of residential buildings are heated with waste heat from nearby industrial plants and waste incineration plants.

The EU strategy also plans to increase consumer power. Owners, tenants, building managers and public authorities will receive more information on how to renovate buildings and transform into more renewable power and the potential benefits of doing so. At the same time, consumer control increases with better measurement and billing and better technology to control energy use.

Regulations in the electricity markets in Sweden, Denmark and the Netherlands are quite similar but the regulations in the thermal markets are different. In Sweden there is TPA (Third Party Access) for access by more heat actors, and TPA can also be introduced in other countries through proposals from the EU. In the other countries there is a requirement for connection to district heating, which is not available in Sweden anymore. In the Netherlands, price regulation is linked to gas prices and in Denmark, it is regulating profitability for district heating companies.

The biggest advantage of a local energy market is to control, through local flexibility, bottlenecks in both power grids and district heating systems, which in turn can reduce the need for large investment for capacity expansion. Better capacity utilization of the electricity and heat infrastructure also enables a larger share of renewable electricity generation in the electricity system.

The heat market is only regulated to a lesser extent, in Sweden as well as in other countries, allowing that voluntary agreement can be made between the actors on trade and storage of heat.

There is already an established local trading venue in Norway where an aggregator can buy and sell flexibility for industrial customers. Some other European projects, like CoordiNet with partners from Sweden, are testing ways to realize flexibility with the Swedish TSO buying services like frequency regulation from aggregators.



A finding from this project and evaluation is that the Fed system should include an actor who has the role of a local system operator. This role should be established for FED.

It is difficult at present, gaining profitability for establishing FED and replications of it in any other city within the EU because of many barriers in regulation and lack of incentives.

6.3.2 Replication strategy

Benefits of a local energy market

The factors having the greatest impact on the Swedish electricity price are hydrological balance, electricity generation, import / export with other European fossil fuel prices and the price of emission allowances. The price differences in the spot market of electricity during the hours of the day are currently too small to have

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any impact on how the end user utilizes electricity. The regulating power market is currently governed by balance regulation of regulatory resources in order to maintain balance in the power system and today provides limited price signals to end users.

In other words, today's electricity market is not built to provide price signals to electricity grid companies and end users to create flexibility and more efficient electricity usage in local electricity grids. A Local energy market (LEM) could provide better price signals to the local actors to act. It can create flexibility in the local power grids through an adaptation of the regulatory framework.

Through flexibility, power companies can optimize the use of energy and power in the local power grids and optimize their investments. By doing so, network companies can also reduce their costs of losses and overlying power grids or, in any case, minimize cost increases that are beneficial to end users.

A Local energy market could contribute to a sustained resilience and delivery reliability as renewable power generation for a larger proportion of the production mix.

The main benefit is that a local energy market should enable higher capacity and flexibility to increase the proportion of renewable energy production locally and thereby reduce CO₂ emissions in the production of energy.

Barriers to establish a local energy market



We suppose that the following barriers exist to establish a Local energy market in Sweden. They are based on the perspective of increasing the flexibility of local energy systems to provide the conditions for new business models as well as developing new system services, also information and knowledge raising activities.

Incentives/Instruments:

- Lack of financial incentives for flexibility for local actors.
- Bad incentives for service and maintenance network companies and investments in new technology
- Lack of incentives for network companies to procure flexibility services.

Roles:

- Unclear roles of actors such as aggregators, balance managers, electricity dealers and online companies. No player today has any real incentive to promote energy efficiency.
- No clear responsibility for flexibility through load management, energy storage, switchable electricity.
- Lack of a definition of what a local energy market is and suggesting geographical system boundaries which makes it difficult to describe the benefits.
- There is no structured cooperation between TSO and DSO regarding current balance in local electricity grids and grid networks required for a larger share of renewable electricity generation at all levels in the grid.

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Regulation:

- Unclear regulatory framework for the ownership and operation of energy storage and taxation in use.
- Difficult to test the regulations and analyze economic consequences for the players in the event of change.
- Difficult assessment of metering data for the operators.
- Missing established trade between multiple energy carriers.

Other:



- There is a lack of knowledge among stakeholders on how price signals work in the electricity market and that price signals meet different purposes.
- Uncertainty about end users having social acceptance and integrity in the exchange of information / data in this kind of trade.
- Uncertainty about lack of loyalty to established energy suppliers in the current electricity market.
- May be a barrier in the absence of any type of IT architecture guidelines as the requirement for IT security increases.

Many of the barriers and obstacles described are valid for both Swedish and European conditions. There is similar legislation for electricity in each country where network companies have monopoly and concession. There are also exceptions for a license like IKN, which is applied in Sweden. What separate Swedish conditions from those of Europe are generally more related to conditions created by instruments and incentives that exists in Sweden.

Activities to help eliminate barriers

Below are a few examples of activities which could be conducted in order to facilitate the elimination of barriers:

- Formulate policy documents that can promote the development of local energy markets and propose the necessary changes to the regulatory framework.
- Arrange seminars to describe the benefits and obstacles.
- Analyse revised EU proposals on Clean Energy proposals and how it may affect Local energy markets.
- Make suggestions to EI and the EU on obstacles that should be eliminated.

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- Analyse R & D projects within the EU and Sweden where the consequences of changes in regulatory framework are looked into.
- Information meetings as knowledge-enhancing activities among end-users.

As part of the work with the strategy for replication a checklist for the locations criteria for a FED system has been developed, see table below.

Table 6-1 Location criteria for FED system

General criteria	Must Have
Ability for interconnection with other integrated energy systems (IES)	Optional
Large enough IES to make the FED system feasible	X
Sufficient know how locally and regionally	X
Business model opportunities	X
Areas / cities / companies present with sustainable profile and ambitions	Preferred
Motivated and engaged actors	X
Network of actors with long-standing relationships	Preferred
Driver of project (actor)	X
Owner of project	X
Trust in project owner / driver	X
Urban region	Optional
Financially strong municipality	Optional
Non-renewable energy production in energy mix	Optional
Area with more than one energy carrier	X
Area with one energy supplier for heat and electricity (or other energy carriers)	Preferred
Financing and capability for increased customer support	X
Willing property owner(s)	X
Strong community feeling	Preferred
Possibility for community solutions	Preferred
Transparency (overcome distrust)	X

The 'Must Have' criteria are mandatory for replication of the FED marketplace. The optional and preferred criteria will allow for easier replication. For clarification, the reason why the possibility for community solution is preferred is because it takes the responsibility from the end users and puts it on the property owners, which reduces the need for public acceptance. Additionally, the cognitive gap of the property owners may be smaller than those of the average property owner, at least in terms of technology for energy.

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6.4 Replication study - Netherlands

A study was performed looking at replication of the FED system in the Netherlands. This work can also give a general indication of barriers and opportunities for replication of FED in a different context than the Swedish.

The overall question that this study tried to answer was: What are the opportunities and barriers for scaling up, through replication and upsizing of the FED marketplace, within the Netherlands, from a national perspective.

The study started with a replication study that identified and classified barriers and opportunities using the framework illustrated in the figure below.

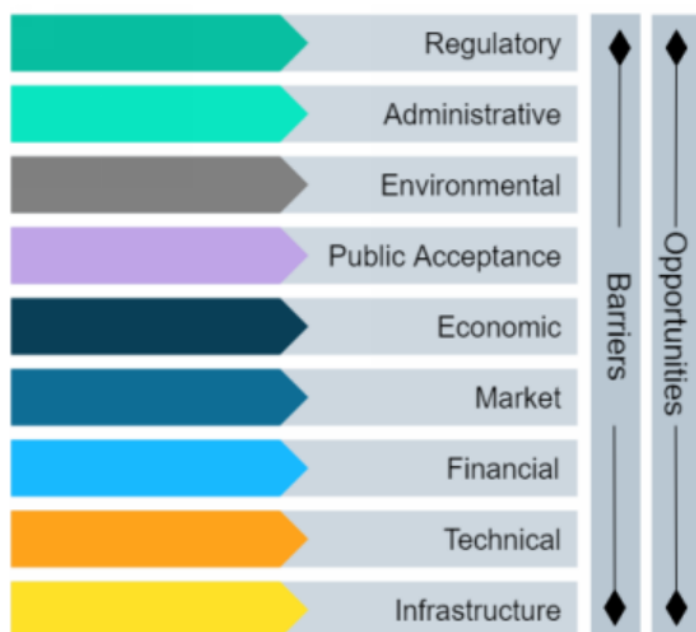


Figure 6-18 Barrier and opportunity framework.

The next step was to perform a comparative study looking at specific conditions for the Netherlands. Lastly additional input and information was gathered from experts through a workshop. The findings from these steps are gathered and presented in the table below.





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Table 6-2 All barriers and opportunities for the Dutch context.

Category	Barrier	Opportunity
Regulatory	<ul style="list-style-type: none"> - Incumbent of policy - Focus on energy efficiency - Government look to industry and vice versa - Allocation of benefits and costs (also non-monetary) - Technology non-neutrality - Focus is on individual solutions - Long term energy contracts 	<ul style="list-style-type: none"> - Mandatory individual metering - Expand role of Authority for Consumer & Market - DSO to collect smart meter data - Green Deal - Focus on CO₂ reduction - Focus on innovation - Focus on natural gas free
Administrative	<ul style="list-style-type: none"> - Lack of definition of responsibility and ownership for the FED system - High level of bureaucracy - Distrust of energy companies 	<ul style="list-style-type: none"> - Energy cooperatives
Environmental	-	<ul style="list-style-type: none"> - CO₂ reduction - Phasing out natural gas
Public acceptance	<ul style="list-style-type: none"> - Lack of awareness and knowledge in general population - Privacy highly valued - Clear communication of concept - Black box solution - Misinformed politicians leads to misinformed public - Turning off of the smart energy meter - Males as primary decision makers within energy sector and industry 	<ul style="list-style-type: none"> - Trend setters - Increasing awareness in general population (and coming generations) - Reduced costs - Community feeling or bond
Economic	-	<ul style="list-style-type: none"> - Product based to service-based - Profit driven on all levels - New business models
Market	<ul style="list-style-type: none"> - Lack of knowledge within industry - Lack of incentives for change - Unstable market for innovative technology - Powerful lobbyists 	<ul style="list-style-type: none"> - Smart Grid research
Financial	<ul style="list-style-type: none"> - Increased cost of customer support 	

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Category	Barrier	Opportunity
Technical	<ul style="list-style-type: none"> - Adaption of FED Market place (algorithms) to Dutch standards - Complexity and connectivity - Technology designed for continuous operation 	<ul style="list-style-type: none"> - Decentralised home heating common - FED can incorporate any energy carrier - Standardisation trend - Smart meter roll-out - Development and improvement of technology
Infrastructure	<ul style="list-style-type: none"> - Current energy system highly efficient and functioning 	<ul style="list-style-type: none"> - Transition to renewable energy production - Large scale renewal

Certain barriers and opportunities are dependent on others, in addition there may be pre-requisites that must be fulfilled in order to overcome a barrier or make an opportunity possible to realise. Two such findings that need to be considered are: smart meter installation and improvement of insulation.



In the Netherlands there is ongoing work with installing smart meters for energy, this type of meters and the possibility to collect measurement data is a pre-requisite for a FED system and constitutes a barrier for replication. An additional concern in the Dutch context is related to public acceptance, due to privacy issues house holders can both reject having a smart meter installed and, if installed, refuse to turn it on.

Improvement of insulation is related to a general focus to improve energy efficiency. This type of action is required to reduce the overall energy use and is a priority. Systems like FED are tools that can help optimise energy use and maybe most importantly provide flexibility and reducing peaks in the energy production and distribution. These types of advanced systems and solutions should only be applied when more simple and direct measures to reduce energy use have been implemented.

Four issues that need to be considered and mitigated if FED is to be replicated in the Netherlands are:

- Physical modifications
- Energy policy
- Market
- Public acceptance

Ways in how this can be achieved are by exploiting regulatory opportunities such as Green deals or internal networks, find willing investors and to identify suitable areas or locations where the existing infrastructure can support a FED system, with proper insulation, smart meters etc. This leaves only specific neighbourhoods, industrial areas, university campuses and similar as realistic suitable areas for replication in the Netherlands in the near future. While the policy and market are relatively easy to influence it is very difficult for a niche product, such as the FED system, to make large scale impact on public acceptance. It is also unlikely that the FED system can have a significant impact on physical modifications, such as



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improved insulation. The conclusion is that the general Dutch neighbourhood is not ready for the FED system.

Proof of concept is still a possibility though. To get a proof of concept up and running the FED project need to address the following:

- Adaption of FED system input values to Dutch standards and context
- Connectivity issues
- Ensure that hourly metering is available and legal
- Communication materials to bridge any and all cognitive gaps, increasing transparency and decreasing complexity
- Finding a suitable location, possible a cluster region
- Define and clarify responsibilities and roles: owner, client, operator and so on
- Define and clarify a business model

Although both Sweden and the Netherlands are located in Northern Europe, this study highlight how many differences there are between the two countries. If two countries that are perceived to be quite similar can be so different, it is likely that replication to non-similar countries will present even greater challenges.

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6.5 Policy recommendations

The FED project has developed five regulatory and policy recommendations supporting the transition into fossil free local energy systems and markets. The aim is to influence regulatory bodies and policymakers to make necessary adjustments in order to enable the realisation of local integrated energy systems.

The five policy recommendations are:

1. Strive for social acceptance
2. Direct investments towards replication of FED through the European Investment Bank and the cities and direct incentives towards cities in order to reduce CO₂ emissions.
3. Define the role of the city / municipality in decision making processes and local energy plans
4. Enable the DSO to trade with flexibility
5. Enable the possibility to test, make demos and proof of concepts in several places

Strive for social acceptance

Problem:



- A lack of knowledge and understanding of local energy markets – how they would work and the benefits they could create.
- Social acceptance is necessary for successful implementation of new technical solutions and the achievement of changed behaviours.
- Local energy markets can contribute to a more efficient use of energy and an energy system with less environmental impact.

Implementation gap:

- Regulations to establish a local energy market are missing.
- Possibilities to trade with multiple energy carriers are limited today.
- Incentives to implement energy communities are lacking.

Policy:

- Local and national authorities need to produce material for information and educational purposes.
- Conduct information campaigns clearly expressing the possibilities with local energy communities.
- The member states within the EU should implement regulations according to Article 16 in the Clean Energy Proposal.
- Promoting local energy markets and the creation of energy communities.

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- Deliver proof of concept of local energy communities, similar to FED which can be replicated to other cities within the EU.

Direct investments and incentives

Problem:

- Cities in Europe are emitting too much CO₂.
- A large share of real estate heating in Europe is individual and consists of fossil fuels as natural gas and coal. These real estates are not a part of the system trading in CO₂ emission rights.

Implementation gap:

- A lack of financial instruments for the cities in Europe to invest in solutions similar to FED, aiming at decreasing CO₂ emissions.
- Large financial differences between the heating of larger systems compared to individual heating (individual solutions cheaper, not included in the emission rights system).

Policy:

- Direct investments through the European Investment Bank (EIB) and local cities to enable solutions similar to FED.
- Design incentives to cities, which are obtained when CO₂ emissions are decreased.

Define the role of the municipality

Problem:



- There is a built-in conflict between the goal of creating solutions which benefit the whole and the aim to optimise locally.

Implementation gap:

- The municipalities are lacking tools to ensure that local energy communities actually contribute to a robust energy system.

Policy:

- Give the cities/municipalities possibilities to influence the design and localisation of local energy communities, so that the overall situation is taken into account.
- Facilitate collaboration between the different stakeholders in the city.

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Enable trading with flexibility

Problem:

- There is no flexibility on the energy market today, which is hindrance to increase the amount of renewable energy and contribute to a fossil free energy society

Implementation gap:

- A clear set of regulations to enable the realisation of flexibility is lacking.
- The roles for the different stakeholders on the electricity market need to be clarified and there are no incentives to push to increase energy efficiency.

Policy:

- Design a set of regulations and incentives for the trade with flexibility services together with stakeholders on the heating market.
- Allow new tariffs and pricing models to enable the use of flexibility services.
- Adapt legislation to new conditions for local energy markets where flexibility will become an important part for the creation of an energy community:
 - Change the Electricity Act in regards to the regulation of the grid in Sweden, allowing for DSO to purchase energy services and including the costs within the revenue framework.
 - Implement exemptions from the concession, as IKN, for local electricity markets.

Enable testing, demos and proof of concepts



Problem:

- Complex system solutions similar to the market solution of FED can be difficult to understand both for potential stakeholders and decision makers because:
 - The solutions are comprised of multiple stakeholders.
 - They, to a certain extent, aim to solve problems which currently are not perceived as problems by many of the stakeholders.



Implementation gap:

- Solutions such as FED need to be made visible to a larger extent.
- There are too few large scale demos.

Policy:

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- Create conditions for new business models for flexibility services with multiple energy carriers by allowing exemptions from current regulations in selected demo projects, on district or city level.
- Enable demos via financing through national and international programs.

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7 RESULTS AND DISCUSSION

This chapter will present results and a discussion of these. The results are divided into parts: the energy system, the energy market, testbed and finally lessons learned.

7.1 The Energy System

One result of the FED project is the actual capacities and maybe most importantly the flexibility that the Energy system provided. Another aspect of the energy system are the amount and types of market participants.

The FED Energy system includes:

- 24 consumers – premises, homes, electrical vehicle charging
- 11 prosumers – solar PV, heat pumps and cooling units
- 2 producers – biofueled heat and power, heat pumps, cooling units, solar PV, turbine
- 16 storage units – building thermal inertia, water storage for cooling, PCM storage for cooling, Li-Ion battery storages
- 3 external producers – electrical, district heating, district cooling

Most of these units were in place on campus before the FED project but have in many cases been updated with additional control, communication and measurement capability. In addition there have been a number of investments in new units as part of the FED project.



An important aspect of the FED solution is the ability to provide and make use of flexibility which allows for moving energy consumption in time to reduce peak loads and/or adapt consumption based on the energy production CO₂ emissions. During this project the actual trading on the market was based on costs.

The FED solution can achieve this flexibility both by using energy storage and by shifting loads between energy carriers. The table below summarises both the overall capacity and demand as well as estimated flexibility per energy carrier.

Table 7-1 Consumption, production and flexibility in the FED Energy system.

	Electricity [kW]	Heating [kW]	Cooling [kW]
Consumption	5 800	14 000	4 000
Production	1 100	15 725	1 740
Flexibility	1 050	1 500	625

Note that the production capacity in this table is the local production, in order to balance the demand and supply side additional energy is supplied to the FED system from the external market. In essence, this means the municipal systems for electricity, district heating and district cooling.

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The flexibility for electricity includes the ability to shift loads to other utilities. This shows that the flexibility in the system is about 10 to 20 % of the overall demand.

As part of the evaluation and to follow up the progress of the project a number of KPI were defined that relates to the Energy System. The target value and the achieved number for each of these are presented in the table below:

Table 7-2 Achievements and target values for KPI relating to the FED Energy System.

Key Performance Indicator	Target value	Achieved in FED
KPI 3 – Local fossil fuel free production	0 %	0 %
KPI 4 – Smart energy and energy efficiency investments (nr of)	10	20
KPI 5- Low carbon / renewable energy investments (nr of)	10	8
KPI 6 – Intermediate energy storage investments (nr of)	3	4

For each KPI except number 5 the target value was reached or exceeded. It should be noted that these are not results of the FED solution per se but rather showcases that the Energy System had a number of additional and significant additions as part of the project that were used during the project and will be used afterwards. The campus energy system has thereby increased its capacity for being more energy efficient, smart, fossil free and flexible.



ENERGY SYSTEM OPERATION

The operation of the energy system here refers to the technical installations and how these have functioned in the buildings and facilities, when controlled by the FED system. Operation in terms of savings in costs, CO₂ emissions etc. are covered in chapter 7.2.

In general, the technical systems have performed as normal and there are no indications that FED control would lead to issues with equipment performance or availability. For each agent the possibility for the real estate owner to manually stop / switch off FED control was implemented. In such cases the building or asset would default to its normal operation mode. The evaluation does not show how often this function was used.

Technical performance is an aspect of the FED system design and implementation that requires careful consideration, especially when including more complex units such as the boilers in Chalmers Power Central. It is important to consider the limitations, how and when the FED system is allowed to control a particular market participant. If including assets such as a large boilers it must be considered within which limits (both capacity and time wise) the FED system can control them. To exemplify, in this project the FED System was allowed to adjust the power output of the main boiler in incremental steps of 10 % for each hourly period within a maximum and minimum level. In other words, FED could not control the start and stop of the boiler but adjust the output when the boiler was in operation.

Operation wise the issue from a technical stand point has been the start up and commissioning phase which in several cases have taken more time and work than expected. This has in the majority of cases been related to communication and measurement and the interface towards the trading platform.

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Another aspect of the operation of the energy system is how this has affected the users. In general the FED system works on a higher level and optimises use of storage and matching supply and demand. This indicates that FED should not impact or be noticed by the end users, the people in the buildings. One exception from this is when using the building thermal inertia as an energy storage. This is because the use of a building as a storage means that energy consumption for the building is moved in time and this will impact the indoor air temperature and thereby the end users. How much the temperature changes depends on the thermal inertia of the building and how large variations that are allowed. The larger the variations, the more energy can be charged and discharged, but at the same time this also likely to increase the amount of dissatisfied end users.

This aspect of the FED system was monitored and evaluated through KPI 7 – Usability of the resulting FED system. This KPI looked at comfort related user complaints before and after FED. The results from this evaluation are shown in the figures below.

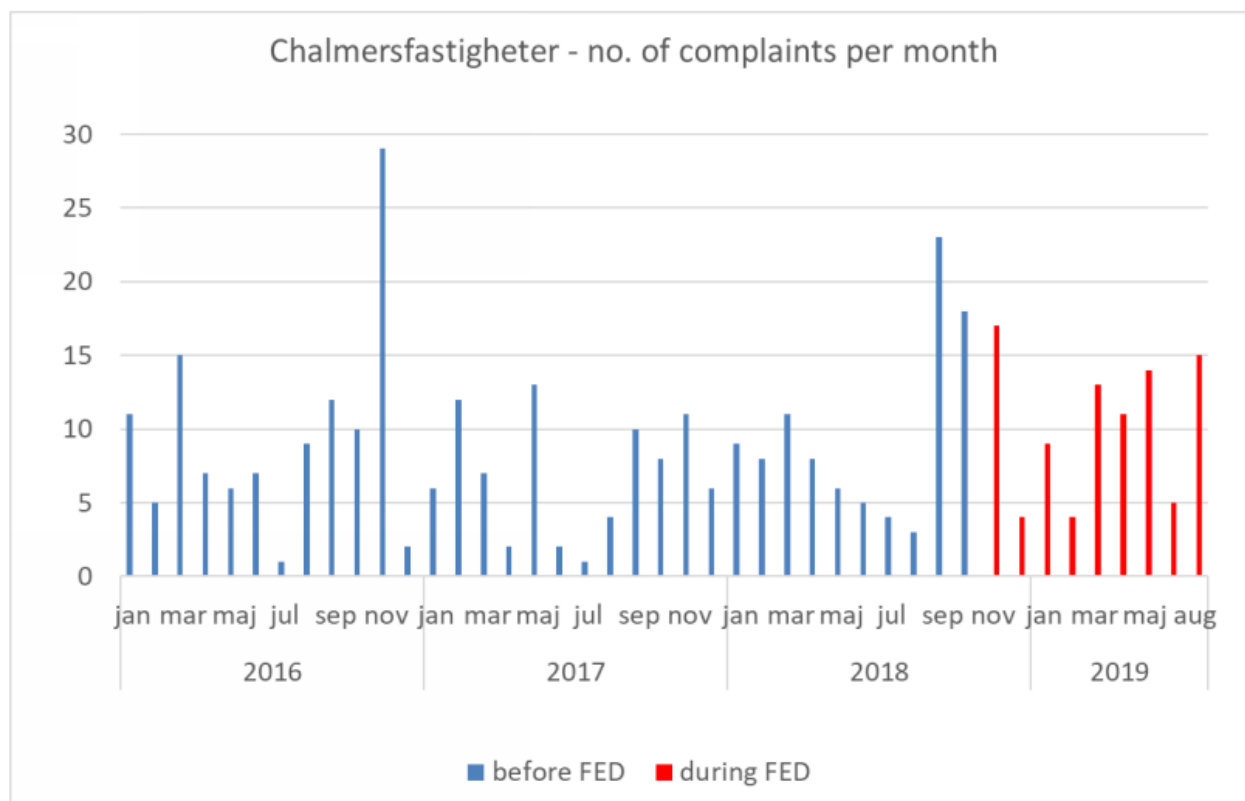


Figure 7-1 Number of comfort related complaints per month for Chalmersfastigheter buildings.

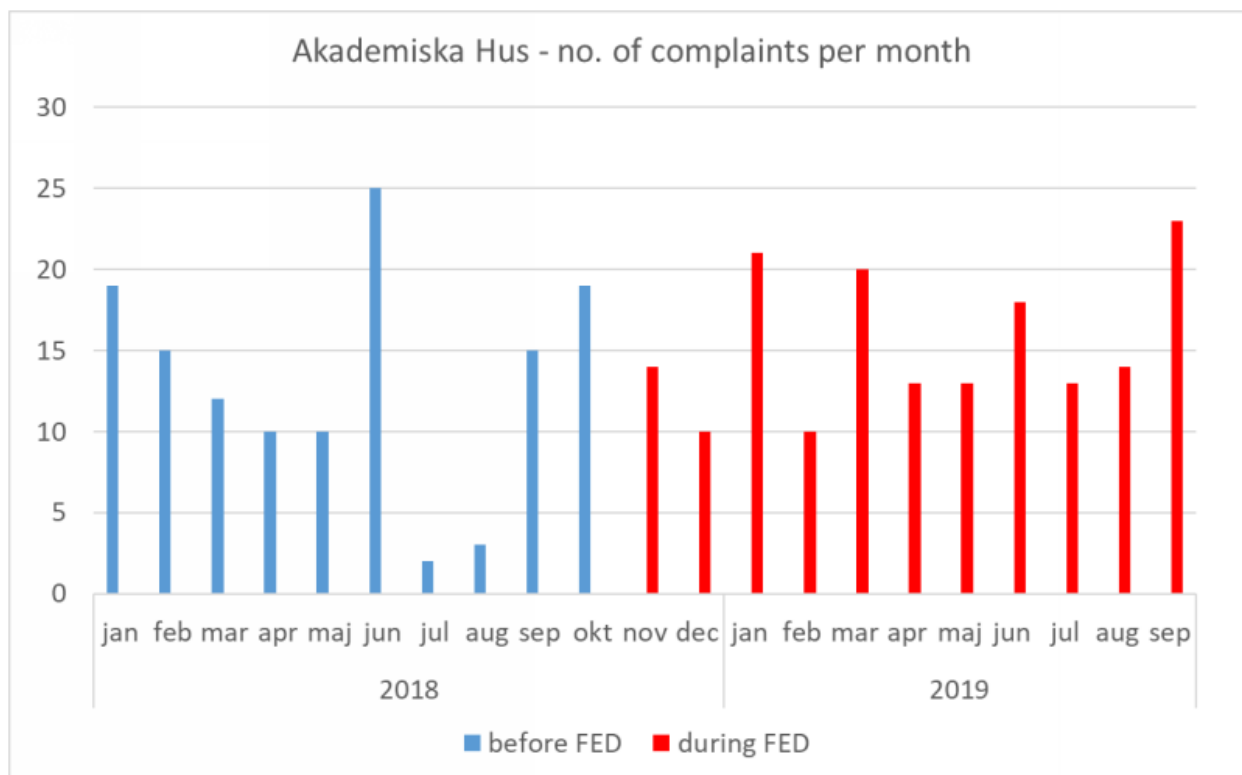




Figure 7-2 Number of comfort related complaints per month for Akademiska Hus buildings.

The result from this evaluation indicates a statistical increase, however the confidence level of this is low (81 and 89 %). The correlation between complaints and outdoor temperature is quite low.

In addition to this an indoor environment survey was performed. This included both students and people working in the buildings. This did not include a baseline measurement but the results are compared to a statistic reference material and indicates that the FED system control has led to temperature variations that has affected the end users.

To summarise these results show that the implementation of the FED system has had an impact on the end users and a decrease in satisfaction related to comfort. However, it is important to note that experience of indoor climate is complex and includes social and psychological aspects as well as physical, and these results shall only be seen as indicative.

One lesson learned regarding the technical systems that constitute the FED Energy system is that to commission and optimise a physical asset as a part of FED takes time. This is a vital factor for replication and future projects building on or developing the FED solution further should either allow for sufficient time and plan accordingly for this phase or consider how to simplify this implementation.

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7.2 The Local Energy Market

In this section the results for the Energy Market are presented. The first part, 7.2.1 describes the identified benefits of the system and illustrates the functions of the market. Next, in 7.2.2, follows the results in terms of performance with a focus on savings in costs and CO2 emissions. Last in this section are how the market has operated, an analysis of the market design and lessons learned regarding the market.

7.2.1 FED Benefits

During the project a number of potential benefits and/or needs of the future energy market that the FED system could provide a solution for have been identified. This section describes six such benefits and provides examples from simulations and actual operation for a number of these. The purpose of this section is to illustrate and show the mechanisms and workings of the FED to help provide an understanding of how the FED solution could work.

One aspect of the FED solution is that it can provide a combination of tools towards one benefit. This means that even if there are other solutions and technologies that can give the same or similar benefit, the FED solution could be more efficient.

Identified benefits:

- Renewable Energy systems
- Fossil peak reduction
- Power shortage
- Grid stability
- Multiple energy carriers
- Local waste heat recovery



Note that there are other possible benefits, but these six exemplify how some of the unique aspects of the FED system can provide advantages compared to other solutions. It should also be noted that power shortage is a potential benefit, this function has not been shown in the project.

RENEWABLE ENERGY SYSTEMS

As the fossil based energy production is phased out the future energy system will include a higher share of renewable energy. Renewable energy production such as wind and solar power is weather dependant and will therefore vary in time which will put high demand on the user side of the energy system to be flexible and adaptable.

The FED system allows for such flexibility and adaptability. Through the optimisation of supply and demand on an hourly level and prognosis of future supply and demand it is possible to adapt and optimise the overall system energy production and consumption towards using renewable energy.

A vital aspect to achieve this optimisation is that the system provides flexibility. The FED system can do this both by utilising energy storages and by being able to switch between energy carriers based on peak

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loads. The FED system optimises this based on the overall system and not on the individual actor (building, storage or production unit).

The advantage of this overall system perspective is that it reduces the risk for sub-optimisation that can occur if each storage or building is aiming to optimise solely based on its own consumption or cost.

FOSSIL PEAK REDUCTION

Peak loads have both a significant economic and environmental impact since these peaks often need to be covered by fossil fuel based production units. There are also capacity issues related to peak power in urban areas where reducing peak loads can be highly beneficial or even necessary.



The FED system can reduce peak loads in the local energy system. Depending on the application of the FED solution this could be applied to local production units within the FED system or towards the external markets to reduce peak loads in the municipal grids, such as district heating system.

In this particular case the benefit is that the FED system should reduce fossil peak loads from imported energy or, in other words, reduce import of energy in times when production in these systems include higher shares of fossil fuel.

By utilising the Market to set up price models, the FED solution can steer and provide incentives for the market actors towards the desired behaviour. The flexibility, primarily the use of storages, and use of hourly updates and prognoses are the tools that the system uses to change the production and consumption.

It should be noted that how well the FED system leads to reduced fossil peaks depends on the price model and how well the prices correlate with the use of fossil fuel. This is likely to be an area that requires fine tuning and adaption depending on the local application of the FED system.

The following example can be used to illustrate this: In this case the Chalmers Power Central (CPC) and one building that includes a thermal storage through thermal inertia are included, see figure 7-3.

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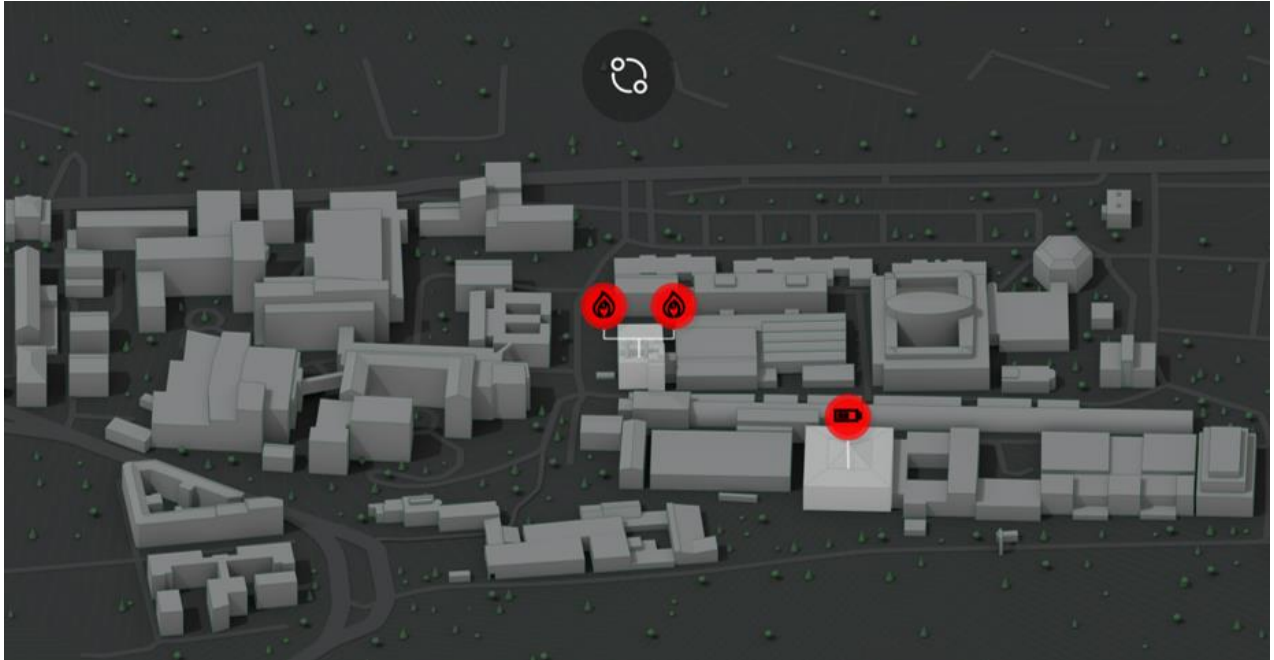


Figure 7-3 Chalmers Power Central and one building with thermal storage.



This case is simulated for a week in May and in the figure below the price for imported district heating, the amount of stored heat energy in the building and the heating dispatch is shown. The heating dispatch includes both imported energy from the municipal grid and local production using the boilers in CPC.



Figure 7-4 District heating price, stored heating energy and heating energy dispatch for a simulated week in May.

Figure 7-4 above shows how the system forecast takes into account a future change in price for imported district heating. The storage is activated and charges the storage before the price peak and the stored energy is then discharged to reduce the peak load and avoid the corresponding peak in price for imported energy.

On the production side the graph at the bottom shows that when the price for imported energy rises the local production increases and for the two indicated times the local production covers all the energy demand and thereby stops the import of energy as the price peaks.

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A corresponding case for the cooling system, this time taken from actual operation of the FED system, is shown in the figures below. Here the cooling is provided by district cooling and as the price for district cooling rises, the cooling storages and building advanced control using thermal inertia responds.

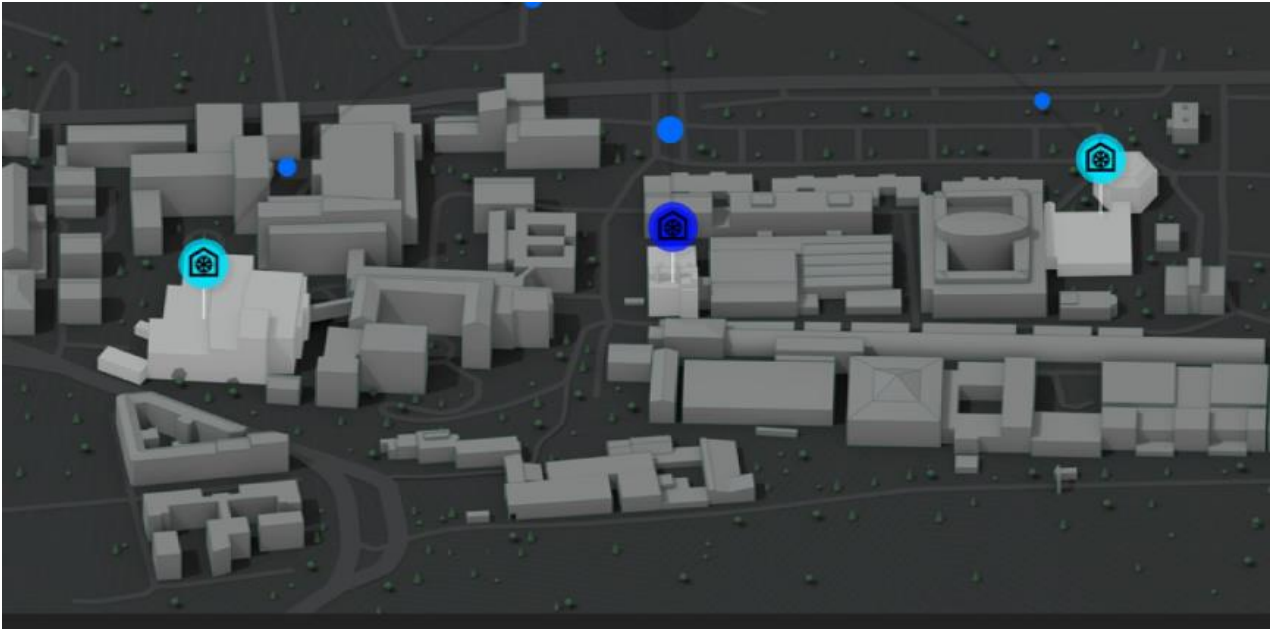


Figure 7-5 District cooling provided through the CPC and two buildings with advanced building control and one cooling storage at campus.

This case is taken from a day in June 2019 and here it is shown how the system uses flexibility provided by the storages and advanced building control to reduce the demand for cooling during the period with an increased price.

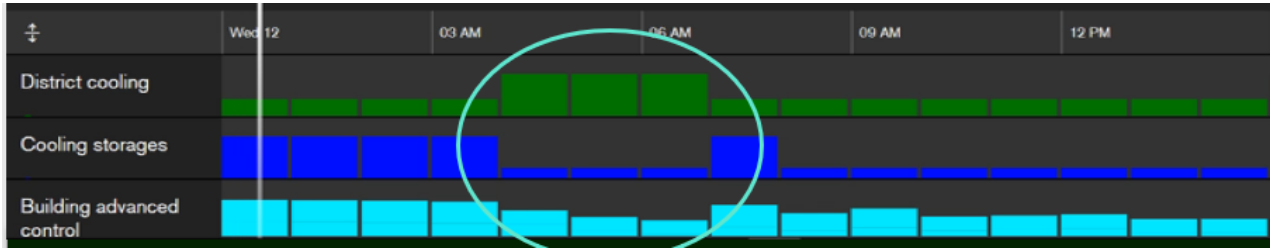




Figure 7-6 Operation case for a day in June showing district cooling price and use of cooling energy for a cooling storage and two buildings with advanced building control.

These two examples show how the FED system can use flexibility both through use of energy storage and the option to switch between imported and locally produced energy to adapt based on the price for imported energy. This shows that the FED system mechanism to avoid peaks are working and that the system corresponds to forecasted peaks as desired.

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How this corresponds to an actual, quantified decrease in use of fossil energy in a practical case remains to be shown. This will depend on how well the price model can be developed to steer the market towards avoiding fossil energy and this in turn will depend on the local prerequisites.

This benefit for the FED system is related to an energy market that includes fossil based energy production and the efficiency and impact of a FED solution in this aspect will decrease as the energy market changes towards more renewable energy.

POWER SHORTAGE

Power shortage in the electrical grid is an issue already today, for instance in Stockholm and Uppsala in Sweden. With the trend of increased urbanisation and growth of cities this issue will become more urgent. Power shortage can refer both to available production capacity and the capacity of the distribution grid. One example of the latter is bottle necks in the distribution system.

The FED system can both reduce peak loads and switch between energy carriers to adapt depending on availability. All bids include a grid location. The market solver has a map of connections with limitations used when creating a solution. Dependencies are not used to reduce bottleneck-related issues, but they are instructions for how multiple bids by the same agent are handled. Examples of this is spreading a certain amount of capacity over multiple trading periods or increasing power consumption when cooling/heating production increase.

Another aspect that is important to handle issues with bottle necks and lack of capacity in the distribution grid is local production. This is an important aspect and driver for local energy markets in general, and that is also a part of FED. By setting up a system and marketplace the FED solution allow small scale production and storage units to connect to the net and market.

The ability to switch between energy carriers within one common market is a unique aspect of FED that can be used to handle power shortage. For instance in cases where there is a peak in electrical load the FED system can switch over to using more district heating instead of heat pumps and vice versa.

Increasing capacity of the distribution grid may require major infrastructure projects with associated costs and impact on the city due to construction work. Material and energy for construction also means that such work has an environmental impact. By reducing the need for such work and investments the FED solution may also help to reduce the overall environmental impact for the energy system.



In similar way as when operating to reduce fossil peaks the FED system can steer the Market actors to reduce the overall power use to the local energy market. This may require a different set up of prices and costs but the mechanisms can be similar as those shown for fossil peak reduction above.

This aspect of the FED system could provide benefits even in an energy system without any fossil fuel based energy production.

GRID STABILITY

In cases where there are challenges with grid stability and performance it could be beneficial to use the local market to help stabilise the larger net. This is mainly related to the electrical market and issues of stability and quality in the electrical grid. But there could also be cases where similar challenges could occur for a district heating net, e.g. maintaining the desired temperature levels.

- Batteries Frequency control as a service
- Solar PV inverters Reactive power as a service
- Steam turbine Frequency control as a service

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The draw back of this solution is that the complexity of the system increases greatly. For instance, the heat pumps in CPC will work towards all three energy carriers simultaneously since they use electricity to produce both heating and cooling. The steam boiler together with the steam turbine will interface both with electricity and heating. The absorption chillers use district heating to produce cooling. This means that it is possible to switch between energy carriers, but also that changing for instance the cooling production of a heat pump will have consequences for how heat is produced and delivered to the system.



To make sure that the FED system makes the best use of the possibilities this gives means that the agents must be complex and take into account all the possible operational modes and limitations.

To illustrate both the complexity and the possible advantages the following case can be considered, see figures 7-8 and 7-9 below.



Figure 7-8 Production and import of energy to Chalmers Power Central. Import of district heating and electricity and production of electricity, heating and cooling.

In figure 7-9 below the heating dispatch, cooling dispatch and prices for district heating and electricity are shown for a simulated week in May.

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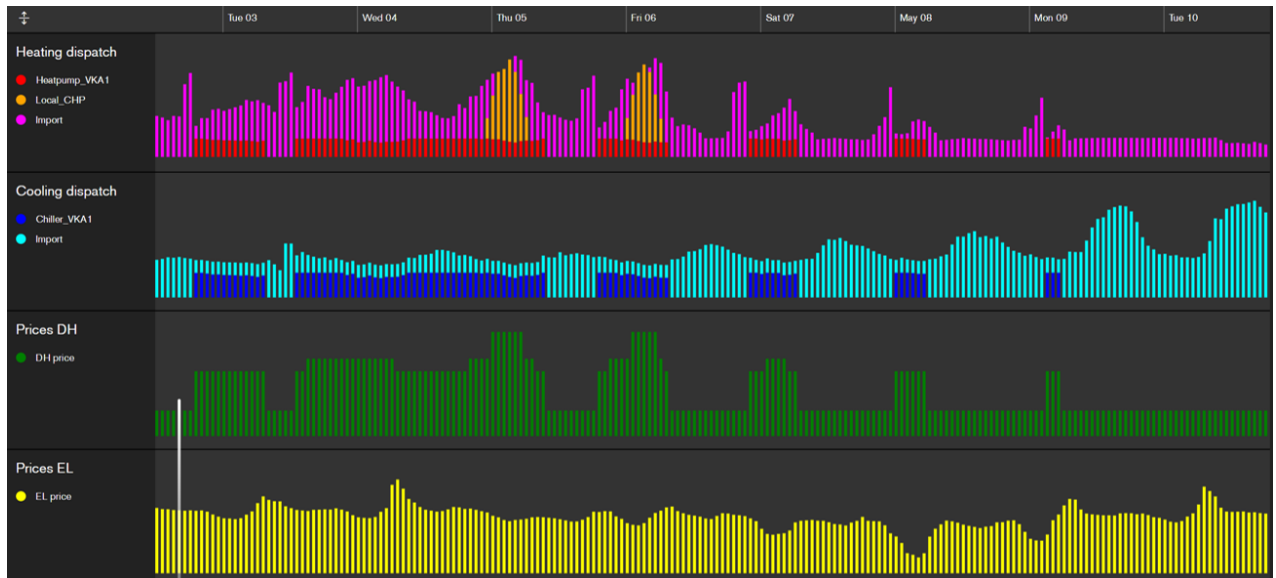


Figure 7-9 Production and import of heating and cooling energy and prices for district heating and electricity for a one week period in May.

In this case, import of cooling refers to cooling being produced in absorption chillers using district heating to produce cooling. So this means that the price of district heating will affect whether using the local chiller or importing cooling through the absorption chillers, as can be seen in the figure.



The figure also shows that when there are peaks in price for district heating the local heat pump is used instead of importing district heating. This can be seen in the heating dispatch where the local production on Thursday covers almost the whole heating demand. However, earlier in the week the district heating price was also quite high but the FED system still chose to import district heating instead of using the local heat pump. A reason for this can be seen in the bottom graph where the electricity price is shown. On Wednesday the electricity price was higher so using district heating was the best option.

The additional complexity is shown by looking the dark red and dark blue parts of the heating and cooling dispatch. These represent a local production unit (cooling and heating pump) that is connected to both the heating and cooling grids. Here one can see that when the FED market algorithm shows that this unit is not cost efficient to produce heating it will also stop contributing to the cooling dispatch.

So multiple energy carriers provide many advantages and potential for greater optimisation than an energy market focusing on a single energy source, but at the cost of a more complex system.

LOCAL WASTE HEAT RECOVERY

Use of local waste heat (or cooling) is an important part of reducing energy consumption and efficient use of resources. The potential for being able to use waste heat is connected to whether or not there exists any simultaneous need for heating and cooling within the system. If not, energy storage can be used to store waste heat.

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In practice there is often an issue with how to handle and value waste heat in a local area, especially when several real-estate or system owners are involved. There need to be agreements, pricing, investments required to connect the energy systems etc.

With a system like FED many of these issues are solved and there is a marketplace where available energy can be offered. A great advantage for the FED solution is that the market includes all energy carriers. As an example of this a grocery store with a large cooling plant can be considered. The cooling machines work to keep the store inventory chilled while also producing waste heat through the condensers. In a FED system such a unit could be included as a local production unit that provides heating. It is possible to control the output of the chillers and produce more heating energy but this will come at a cost in electricity. In a normal case, without a FED market, there will be no correlation between the price in electricity and heating meaning that the owner of that system can be asked to produce additional heating at a time where electricity prices are high. In a FED system both electricity and heating prices would be considered which would be an advantage for such local waste heat sources.

Since one of the main ideas of local energy markets are to allow for small scale producers to connect to the market there is a great potential to take advantage of waste heat and to make it economically viable. It may even be so that systems such as FED may be optimally used when implemented where there are simultaneous need for heating and cooling, in other words when there is potential for making use of waste heat or cooling.



7.2.2 Performance

Arguably the most important aspect of the FED Market is to provide a cost efficient way to reduce CO₂ emissions. However, another aspect that may be equally important is how the FED solution can provide an answer to the requirements of the future energy market. This was described in 7.2.1 above and is related to an energy market with higher share of renewable energy production as well as increased local production in combination with issues relating to the distribution grid.

In order for a solution such as FED to be replicated and implemented it must be shown to be economically sustainable. If it is not cost efficient there will be no incentive for real estate and production unit owners to invest in such a solution. But it should also be noted that even if this was one aim for the FED project this is a highly innovative project trying out new technologies and a unique market in a early stage of development. Therefore it may be more beneficial to regard this project as a pilot project rather than as a test of a commercial solution ready to be implemented.

During the FED project the energy system has operated in real time, trading and controlling actual energy supply and demand. But it has not implemented actual billing based on this trading. The price for the actual energy being supplied has followed the existing agreements and contracts between the campus actors, i.e. Akademiska Hus, Chalmersfastigheter and Göteborg Energi. Due to this it has not been possible to measure and follow up the actual costs and savings in this project.

In actual operation the FED system was run based on cost optimisation. Other operation modes, such as minimising CO₂ emissions or use of primary energy, has not been tested.

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COST SAVINGS AND CO₂ EMISSIONS – FROM SIMULATIONS

Evaluation of costs and CO₂ emissions for the FED system as a whole has been evaluated by simulations. The simulation model allows for simulating individual assets or all assets both in terms of operating cost and CO₂ reduction. Since this is a simulation one should note that this may not be fully representative of the actual outcome of a FED solution implemented in actual operation. Rather, this should be seen as an indication of the potential what could be achieved in an ideal situation.



In the FED project two different cases (academic and so called industrial) was considered when attributing CO₂ factors to energy sources for evaluation. The main difference between these two methods are how they allocate CO₂ emissions to the use of industrial waste heat, where the industrial case states that use of waste heat does not have any CO₂ emissions. For the results presented in this report the academic case has been used. Using the industrial case does not lead to any significant changes to the simulated results.

Also, these simulations include both new investments in PV panels, energy storages and energy efficiency measures from the advanced building control systems in addition to the FED market. So these results include more measures than just the FED market and due to the interactions and co-dependency of the different parts of the system it is not possible to single out the impact of the market by itself.

Two different studies and their findings are presented below. The first study looked at the impact of FED and the investments made compared to alternative scenarios, the second study looked at how introducing a CO₂ factor, i.e. a CO₂ tax, to the FED system could steer market behaviour.

The first study included the following scenarios:

- Scenario 1 - Business as usual (BAU)
 - Historical dispatch of production units (i.e. how the units are operated) and historical demand. This scenario is used as a reference case, two sub-cases were simulated: a) using seasonal prices of district heating and average emission factors (1a) and b) using hourly spot prices for district heating and marginal emission factors (1b)
- Scenario 2 – Redispatch no investment
 - This case simulates the system as it is today, without FED investments, these scenarios compare BAU with an optimised case, i.e. changing the operation in all production units in order to minimize the operational costs. Case 2a) compare costs using actual tariffs for the real estate owners (seasonal prices). Case 2b) compares cost using marginal prices.
- Scenario 3 – Redispatch with FED investment
 - This case simulates the optimal dispatch of the FED system including all investments made in the FED project, this is only done for the case with marginal spot prices and emission factors.
- Scenario 4 – Redispatch with investments in building flexibilities

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- This case simulates the optimal dispatch when only investments in building flexibilities are done. It uses marginal prices.

So this study compares the FED system both with a reference case where things are operated as they are now (BAU) and with cases where the current system is operated for cost efficiency and lastly a case with a system including investments operating to create flexibility by using thermal storage. The results from the simulations are shown in the figure below:

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 4a
	BAU (season)	BAU (MA)	No investments (season)	No investments (MA)	FED investments (MA)	Thermal storage (MA)
Peak CO2 emission (Average) (g CO2)	1 319 682	1 319 682	1 226 315	1 226 315	1 008 433	1 171 609
Total CO2 emission (Average) (g CO2)	2 734 227 312	2 734 227 312	2 742 589 541	2 886 261 306	2 439 231 771	2 877 942 468
Total PE (Average) (kWh)	90 287 775	90 287 775	87 009 112	84 628 279	84 194 700	84 440 282
Peak CO2 emission (Marginal) (g CO2)	2 441 571	2 441 571	2 136 403	2 136 403	1 442 845	1 865 589
Total CO2 emission (Marginal) (g CO2)	1 920 558 555	1 920 558 555	1 913 899 383	1 907 081 034	1 607 267 725	1 907 384 514
Total PE (Marginal) (kWh)	57 349 893	57 349 893	52 370 977	49 660 898	49 977 652	49 421 906
Total variable cost (kSEK)	29 103 112	29 020 022	27 645 639	27 575 700	26 795 842	27 485 712
Annualized investment cost (SEK)	-	-	-	-	2 293 863	25 667

Figure 7-10 Simulation results for the four scenarios.

For the simulations both average and marginal emission and primary energy factors have been used. For electricity the data comes from electricity map, for district heating Göteborg Energi have provided the data and for local production most data come from IINAS 2015 and DEVCCO.

In the above simulations the dispatch of the different units (buildings and production units) in the FED system are modelled in order to reduce the annual variable cost as much as possible. The emission and primary energy reductions are presented both for marginal and average emission (i.e. average emission for each hour). The marginal values indicate the emissions from the unit that are on the margin and can be seen as the actual influence the FED system would have on the surrounding systems.

The BAU case is used as a reference case and presents the costs and emission for the FED system without any changes in how the system is operated. It is important to note that the prices used in the optimization model does not fully correspond to the price paid by the real estate owner and may not fully agree with the actual costs for the real estate owner.

The resulting reductions are shown in graphic form in figure 7-11 below:

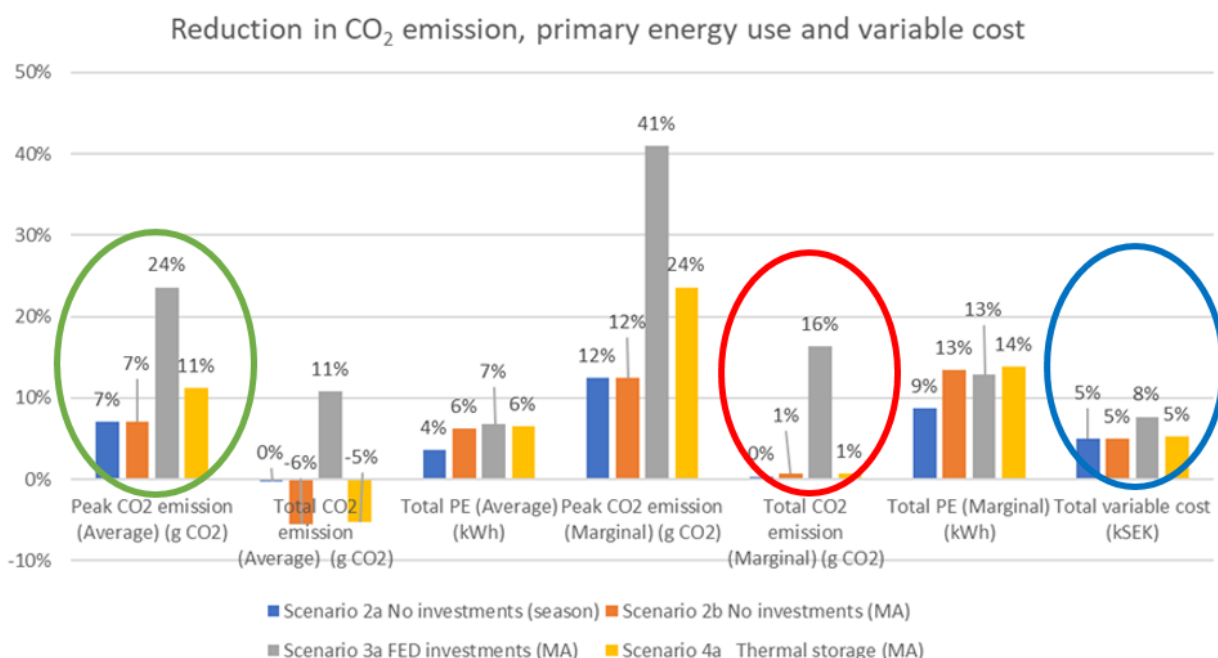


Figure 7-11 Reduction in CO₂ emissions, primary energy and variable cost for the different scenarios considering marginal or average emission / primary energy factors.



These results show that it is possible to reduce costs by approximately 5 %, this could be achieved without additional investments (see scenario 2a and 2b in the blue circle). Similar savings in cost are also possible to achieve using the FED system or by utilising thermal storage.

When looking at reducing CO₂ peaks the FED systems shows the highest potential reductions, compare the bars in the green circle. However, scenario 4a provides quite significant reductions and the investment required is relatively low.

An important aspect of a future energy system are the total CO₂ emissions; this is the actual impact on the environment and must be considered. In this case the FED system scenario with investment was the only one that could provide a reduction in total CO₂ emissions. When considering marginal spot prices the FED system decreased the total emission by up to 16 %, see the red circle in figure 7-11.

Some of the conclusions made from the simulations are:

- The largest reduction in the variable cost comes from the fact that the production units are operated differently with the FED system compared to the reference case, which also affect the imported / exported energy.
- The yearly variable cost are reduced further when using the thermal inertia of the buildings and it is in comparison a low cost of investment.
- The reduction in CO₂ emissions also shows the largest reduction from operating the buildings with the investments made in the FED project, both the total and the peak.

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The results from the simulations indicate that the FED Market can provide reductions in costs as well as CO₂ emissions.


The second simulation study uses a different set up of scenarios:

Scenario	CO ₂ factor
BAU	The energy system operated without the FED investments and the FED market
Min PE	Minimize the primary energy usage
No CO ₂ factor	No added CO ₂ factor
Low CO ₂ factor	CO ₂ factor =0.1 SEK per kg CO ₂
Mid CO ₂ factor	CO ₂ factor =1 SEK per kg CO ₂
High CO ₂ factor	CO ₂ factor =10 SEK per kg CO ₂
Extreme CO ₂ factor	CO ₂ factor =100 SEK per kg CO ₂

These scenarios are focused on CO₂ factor and investigating at what level such a factor would be most efficient. The CO₂ factor could be viewed as an additional CO₂ tax. The scenarios ranging from 0.1 SEK per kg CO₂ to 100 SEK per kg CO₂, which could be compared to the current levels of the European emission trading system approximately 0.25 SEK per kg CO₂.

From the case without the FED system the highest peak was 3 250 946 gCO₂. The change in CO₂, cost and primary energy is presented for the different scenarios compared to the BAU scenario.

The total costs, presented in figure 7-12, represents the total operational cost of the units, including fuel cost, maintenance cost etc. It does however not represent the cost paid/received by the agents/units in the FED system, i.e. the marginal cost of the system. Note that these results differ slightly from the results presented in figure 7-11, this is partly due to updates and adaptations to the simulation model.

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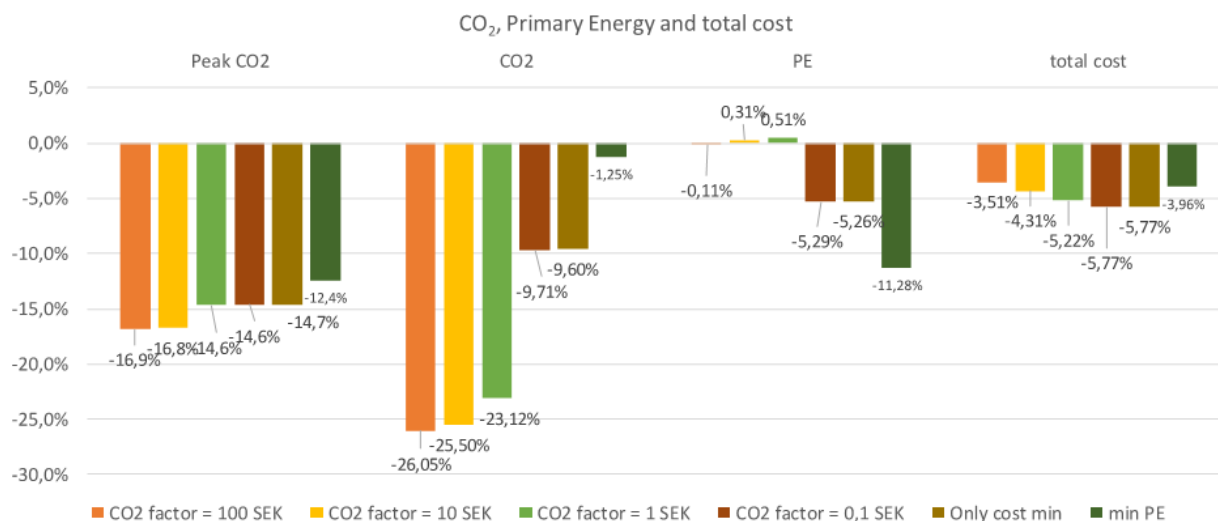




Figure 7-12 Reduction on CO₂, primary energy and annual cost for the FED system compared to a BAU scenario.

These results show that cost will be reduced in all scenarios, between 3.5-5.8%. The highest reduction is as expected for the scenario without any CO₂ factor. In monetary terms the reduction varies between 1.0 - 2.6 MSEK. A large share of this cost reduction is due to the installation of solar PVs (approximately 880 000 SEK).

In addition, both peak and total CO₂ emissions are reduced for all scenarios. What is clearly shown here is that a CO₂ factor can have a significant impact on the total CO₂ emissions. It can also be seen that going from a mid to an extreme factor does not significantly increase the reduction of CO₂ and when regarding costs an extreme factor will decrease the potential cost savings.

No detailed study has been conducted on the changes for individual agents. However, by analysing the marginal cost for the district heating system it was found that the average marginal price for importing heat to the FED system decreased from 0.37 SEK/kWh to 0.33 SEK/kWh and for exporting the price increased from 0.31 SEK/kWh to 0.36SEK/kWh. This indicate a potential for reducing cost for energy for an individual market actor. Additionally, these results indicates a reduced use of expensive production units for the district heating.

From an energy storage perspective, the usage was limited when only cost optimization were considered. However, with the CO₂ factor the usage increased rapidly. The reason for this is due to the larger variations in CO₂ emissions compared to the energy price. The energy storage results in increased losses and hence large price variations is needed in order to make it profitable to operate. Comparing the energy losses from batteries with the building inertia energy storage the losses are assumed to be lower for the batteries i.e. 10% compared to on average 22%. On the other hand, with the advanced building energy storage the energy consumption is reduced due to the energy savings gained from the improved control of the indoor climate.

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Regarding the primary energy usage the simulation show that a primary energy reduction of around 5% is expected. By steering the market towards primary energy reduction (e.g. by including a primary energy factor in the market) a reduction of up to 11% can be achieved. Steering the market towards a CO₂ reduction will on the contrary reduce the possible primary energy usage reduction. One reason for this is that some units have low CO₂ emission but high PE factors, e.g. biomass boilers have low CO₂ emissions, but high PE factors compared to e.g. natural gas boilers. This is based on the agreed factors for PE used for analysis in this project (these are based on the energy allocation method with some corrections based on Miljöfaktaboken, Värmeforsk).

RESULTS FROM FED OPERATION

The results from the actual operation of the FED system has been evaluated by the real estate owners, measured progress through KPI and as part of other studies performed.

Real estate owners analysis

As described earlier in this chapter the actual operation of FED did not include billing and thereby the trading did not include actual costs and revenue for the real estate owners. But Akademiska Hus has collected data regarding energy and power for the electricity, heating and cooling systems for the FED test period and compared to previous year. The comparison and analysis were done for each building and production unit, here only the results for the overall system are presented.

In the two following figures the total power and energy in the campus area for each energy carrier is shown. The data for these figures are based on monthly reports in Akademiska Hus system for energy and are collected for the period 2018-01-01 to 2018-07-31 and compared with the corresponding time during 2019.



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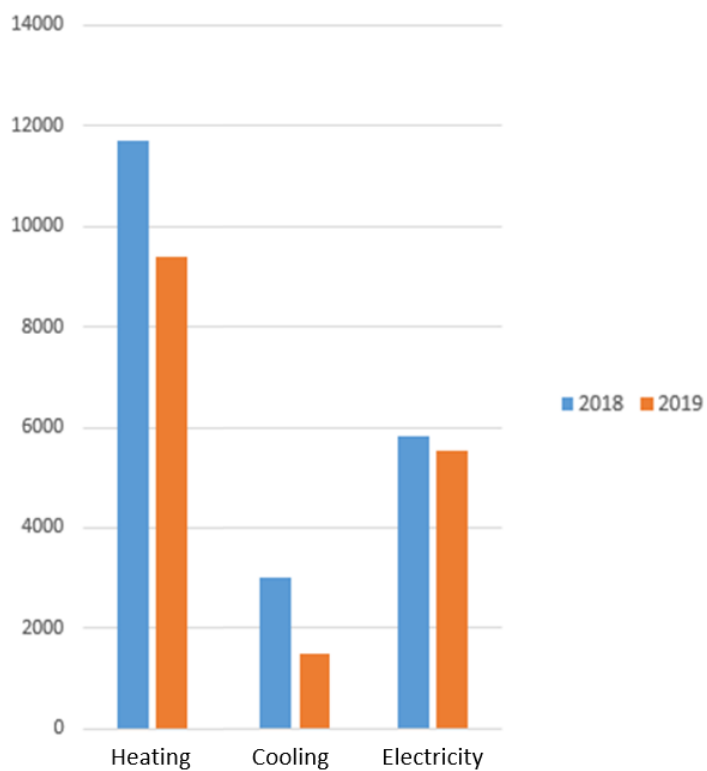
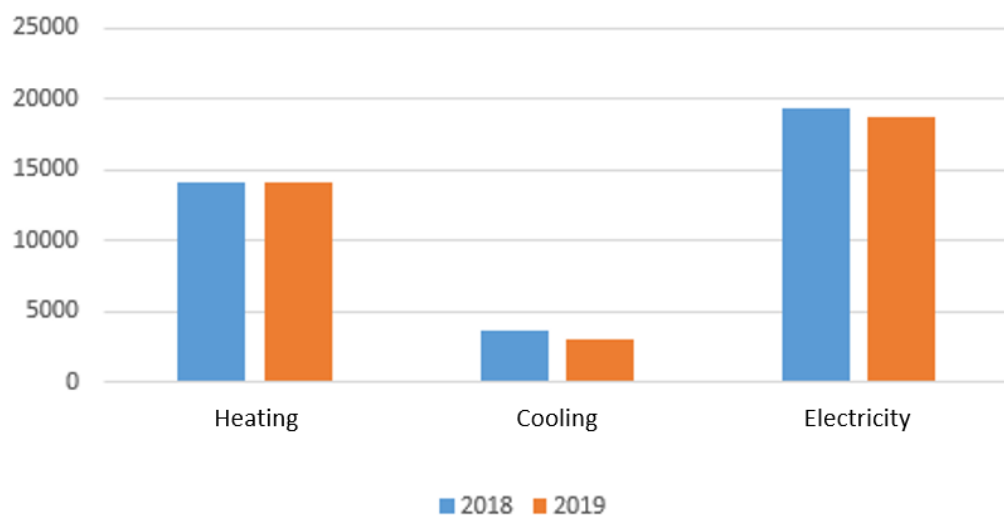


Figure 7-13 Total distributed power in kW for each energy carrier for the same period in 2018 and 2019.





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Figure 7-14 Total energy in MWh for each energy carrier for the overall campus system for the same period in 2018 and 2019.



This analysis shows that during FED there has been a reduction in peak loads for heating and to a smaller degree also for electricity. For electricity the reduced peak load is due to the solar panels and local production of electricity at the campus area. When it comes to cooling power it is more difficult to see the impact of FED since cooling power to a high degree is determined by the outdoor temperature. As 2018 had a long period with unusually high temperatures it is difficult to compare data from that year with corresponding period during the FED project.

When looking at energy use it has not been possible for the real estate owners to see an actual reduction in energy use due to FED. The analysis is further complicated by the fact that the real estate owners are working with increasing energy efficiency and a number of such measures were implemented during FED. When it comes to the advanced building control systems that were included as part of FED they also contribute to the energy efficiency of the building itself by optimising energy use. This means that it is not straightforward when looking at actual energy use of the building to determine what is the result of FED.

Progress measurement - KPI

As described and illustrated in chapter 7.2.1 it has been shown that the actual FED system includes, at least partially, the desired functionality to utilise flexibility both by switching between energy carriers and using energy storage to optimise the system as a whole. A question remains if the system in practice can make sufficient use of these functions to bring the expected results. This has been evaluated through the progress reports and measured especially through KPI 2 Fossil peak reduction.

Analysis of the result (as of December 2019) show that the FED system in operation during summer season has not shown any reduction of CO₂ emissions as defined for KPI 2. This KPI focuses on the top 5 % of the highest peaks for CO₂ compared to a calculated synthetic baseline. Figure 7-15 shows the baseline and outcome for the FED system for a two week period in August 2019.

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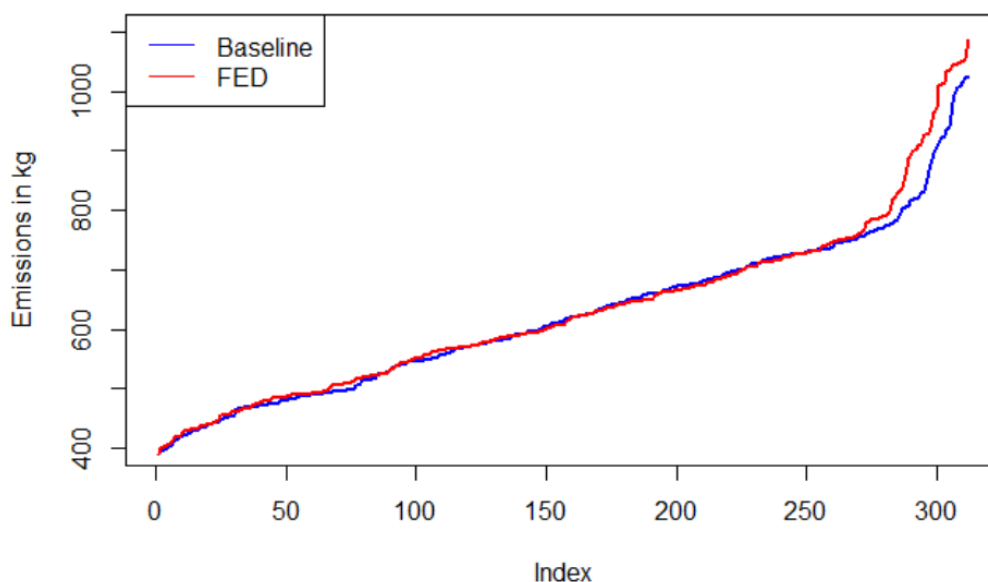




Figure 7-15 CO₂ emissions for the FED system and baseline for a two week period in August 2019.

Figure 7-16 shows a summary of the results for the same two week time period.

Academic case	FED	Baseline	Difference
Total imported CO ₂ for the time period	196.6 tonCO ₂	194.1 tonCO ₂	+1.2 %
Average top 5 % CO ₂ peaks	17.2 tonCO ₂	16.1 tonCO ₂	+6.8 %
Highest CO ₂ peak	1.09 tonCO ₂	1.03 tonCO ₂	+5.8 %
Industrial case	FED	Baseline	Difference
Total imported CO ₂ for the time period	176.9 tonCO ₂	178.3 tonCO ₂	-0.1 %
Average top 5 % CO ₂ peaks	13.4 tonCO ₂	13.6 tonCO ₂	-0.2 %
Highest CO ₂ peak	0.87 tonCO ₂	0.96 tonCO ₂	-9.4 %

Figure 7-36 Summary of results for KPI 2 for a two week period in August 2019.

However, when analysing results for FED operation for the period January 1st to April 30th the results were very different. It should be noted that there were issues with the quality of the data collected during this period and in addition there were issues with performance from several market actors, therefore there is no summary of results for this period. But analysis of data from this period indicate that FED system for this period has reduced both the total CO₂ emissions and highest CO₂ peak by almost 20 %. Though similarly as for the shown results in figure 7-16 above, when looking at top 5 % of the CO₂ peaks the FED system had not led to any reduction.

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Even if these results are only indicative these reductions in total and highest peak of CO₂ emissions for the actual FED system during heating season are in the same order of magnitude as the simulated results.

So as these summaries show the results for the FED system are not straightforward to interpret. It seems like the FED system can lead to significant reduction in CO₂ for the heating period but not during summer when cooling is required. One part of this can be that during cooling season the available flexibility is much more limited and thereby there is less that the FED system can do.

These results show that the reduction of CO₂ for the FED system in operation are less than the potential shown through simulations. At this stage it is not clear why the simulations and actual operation differ as much as they do, nor is there a full analysis of how the achieved results stands when compared to the project goal.

One important aspect regarding this is the price model and how well the prices correlate with CO₂ emissions. This applies both to the pricing of energy imported from the external (municipal) grids and the locally produced energy, additionally the balance in pricing between energy carriers and between locally and externally produced energy needs to be correct. Since FED in operation is only working towards costs this is a vital aspect and will determine whether or not the actual system will lead to reduced CO₂ emissions. Göteborg Energi prices are used for district heating and electricity from the municipal grid and these do reflect the CO₂ intensity of their production units. But there remains a question regarding the prices for the local production units in the market and how well these reflect the CO₂ intensity and how they balance with Göteborg Energi prices in the market. This could be, at least partially, a reason for why the FED operation does not show the same reductions as the simulation.

It should also be noted that the campus energy system together with Sweden national energy mix is already quite CO₂ efficient. In other words, it may that the ability of the FED solution specifically to reduce peaks in CO₂ emissions is limited due to the local prerequisites at the campus. However, this need further investigation to see how the FED system would function if implemented in a system where a significant part of the energy production is fossil based.

Another area that could be part of this is how well the agents and set up of bids and bid dependencies reflect the actual physical assets and the flexibility provided by them. The system is complex and this solution is one of a kind with limited previous experience that could be used to develop the agents and bids for each asset as optimal as possible. Whereas the simulation model may be said to represent an ideal case the actual operational system includes some necessary limitations and constraints as well as compromises and simplifications that removes it to some degree from the idealised version. This is likely part of the reason for the results deviation from the simulation.

Operational analysis and validation

Due to the complexity of the FED system as a whole it can be both helpful and necessary to study sub-systems separately in order to analyse and validate the performance. Below is a figure showing the district heating system bids and cleared capacity for a 24 h period in November 2019.

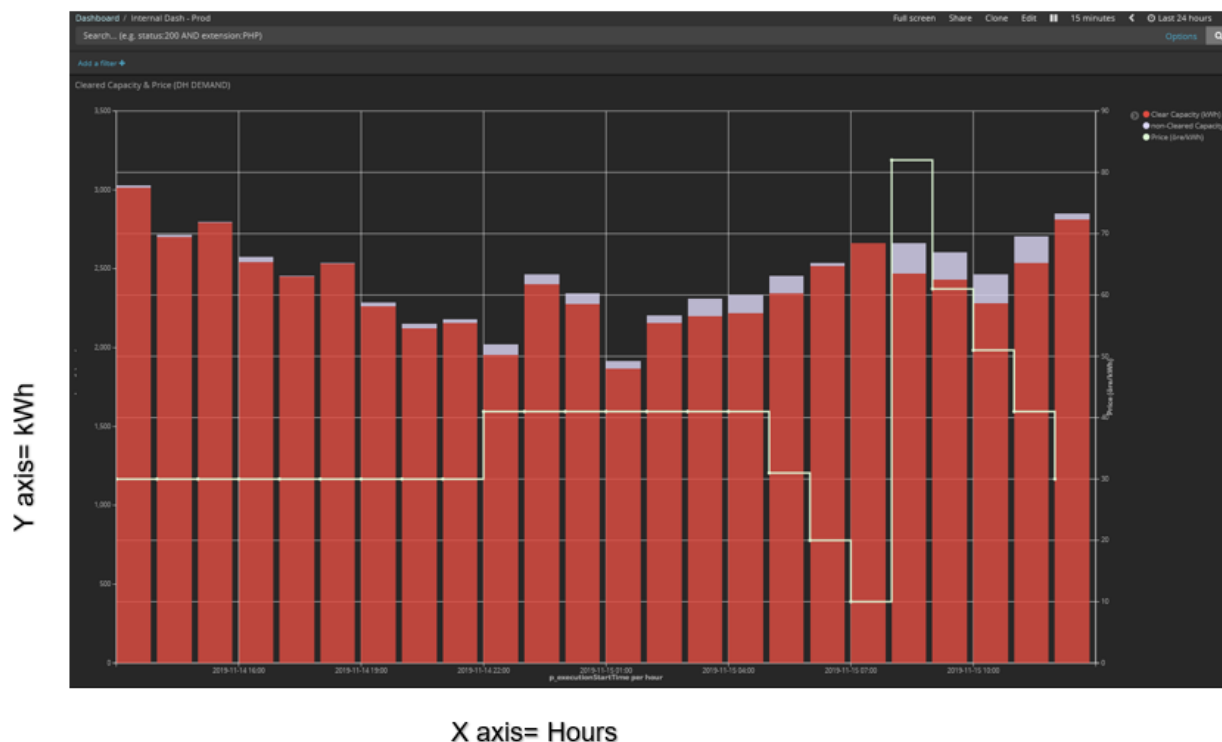




Figure 7-17 In red the sum of all cleared capacity (in kWh) of district heating demand is shown, and in lighter grey the amount of non-cleared capacity for the actual hours. The white line shows the average price, expressed in the Swedish currency öre/kWh, i.e. 1 öre/kWh is ~ 0,1 cent/kWh.

In this figure the sum of all cleared capacity (in kWh) of district heating demand is shown in red, and the lighter area represents the amount of non-cleared capacity (not supplied) for the actual hours. The white line shows the average price, expressed in the Swedish currency öre/kWh, i.e. 1 öre/kWh is ~ 0,1 cent/kWh.

When the price falls, there is an increase in the energy used. As the price increases so does the amount of non-cleared capacity, this represents that the system uses the flexibility to not buy energy when the price is high. The available flexibility offered by the agents are used in the market to optimize the total cost in the system, and the sub-system response is therefore as can be expected.

It can also be seen in this example how the FED system works to reduce peak loads in connection with an external market. In this case consider that the district heating price is connected to the use of an expensive production unit, which is typical for a production unit that serves to meet peak demand. The FED system recognises that the peak will occur and shifts load to times with lower price as shown in the figure.

A comparison of how the actual operation of the FED system with the optimal operation obtained by the simulation model was done. This looked at the time period 2019-08-19 to 2019-08-31. During the evaluated time period (2019-08-19 – 2019-08-31) there were no heat demand and the cooling were produced by the cooling heat pump and the absorption chiller. Figure 7-18 presents how the absorption

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chiller and heat pump units were operated during two weeks in August, together with the district heating price and electricity price. Figure 7-19 show the same time period and data from the simulation model.

As can be seen the cooling produced from the heat pump is generally lower when the electricity price increases and increases when the price decreases. The simulation model would operate the units in similar way but would increase the output from the absorption chiller when the cost of district heating is low much more than in the real operation. In terms of annual production, in the simulated case the absorption chiller produced about 5.2 % more than in the real operation while the heat pump reduced its production by approx. 14.4 %. In terms of cost it was found that with the simulation model the cost was found to be 0.3 % lower than the actual operation of the FED system. Although some variations were observed in the operation it does not have a great impact on the cost.

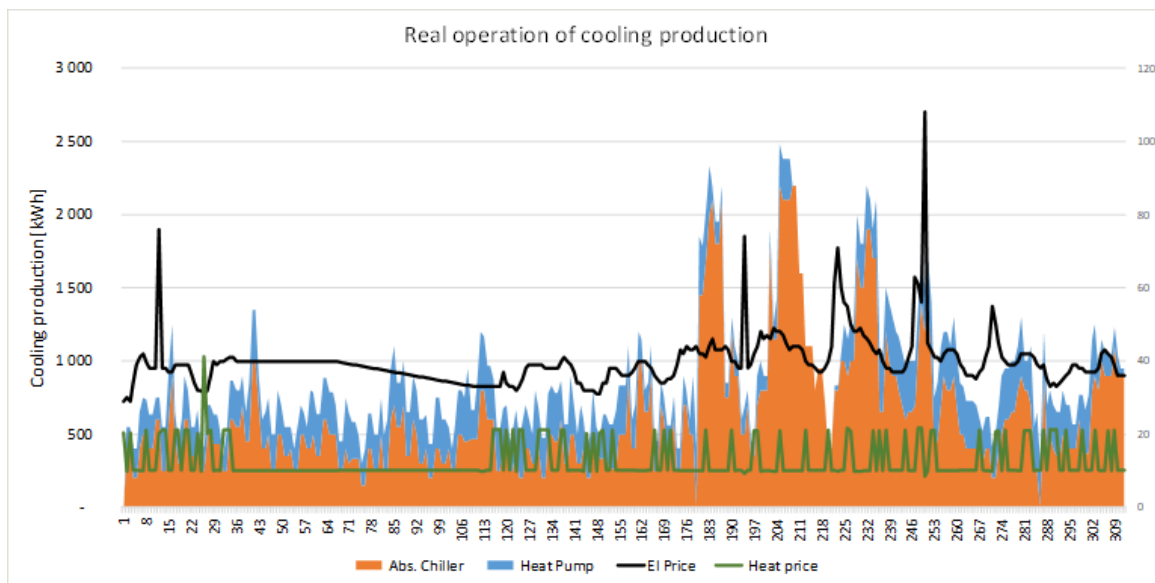



Figure 7-18 Operation of cooling production.

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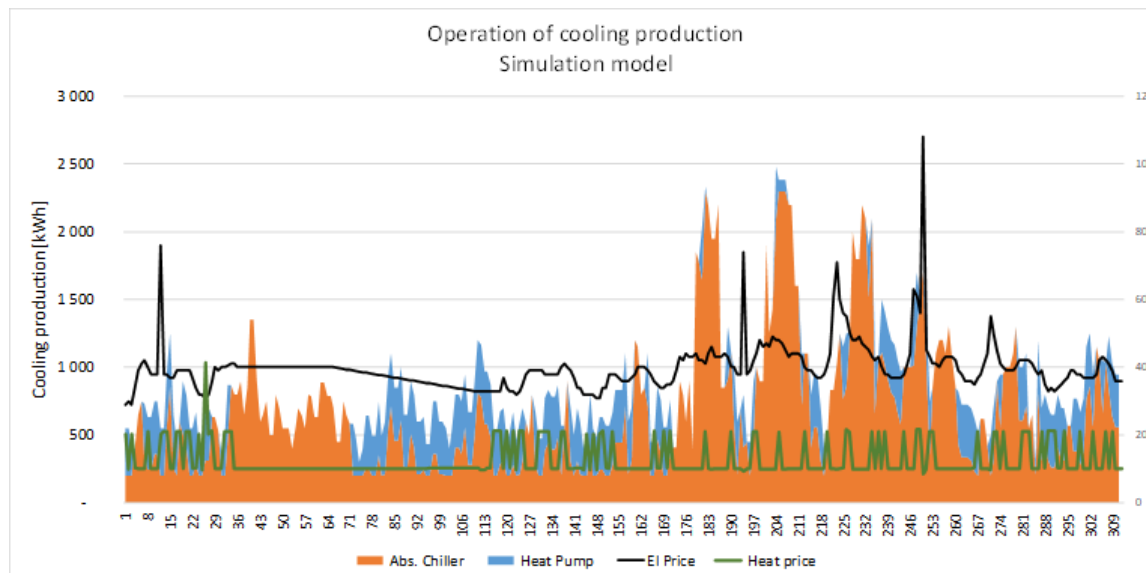


Figure 7-19 Simulated cooling production.

This analysis shows that the operation here is in general very similar to the simulated system. But it was found that in the simulation model there are larger variations in how the production units are being operated compared to the actual operation. This is quite expected since in operation there are more limitations due to equipment performance and safety as well as system inertia and other factors that are difficult to fully represent and accurately model in the simulation.

HANDLING DEMANDS FOR THE FUTURE ENERGY MARKET



How the FED system meets the demands for the future energy market can not be quantified but a qualitative discussion is possible. What importance to put on these requirements may depend on both the local prerequisites and how fast one expects the development of the energy system to be. There may not be one single definition and all inclusive definition of what a future energy market will include but here three aspects has been identified:

- Higher share of renewable energy production
- Increased amount of local energy production
- Distribution system capacity issues and constraints

The future energy market need to include more renewable energy production to replace fossil based energy. This means that the energy production will be more varied.

Issues with capacity in distribution systems is a very real problem and with increased urbanisation and densification of cities. This can both be related to overall capacity and local bottlenecks in distribution systems.

The FED system has shown that it can both provide and trade with flexibility and, importantly for this case, do this in connection with external systems.

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With regards to local production and storage FED has shown that it technically can include small scale units together with major production units in one common market. The system and market design shows a solution for achieving this. This aspect could also include local waste energy to be traded on the market. Today a barrier for optimally make use of waste energy is to have a business model and way to value and trade for such energy. The FED solution could be one solution to this barrier allowing for more efficient use of waste energy.

Distribution system capacity and constraints are included as part of the FED design by including dependency bids and also take into account the distribution system in the market. This function has been shown in actual operation during cooling season. Many bids were put on the market which lead to an issue with distribution capacity, the FED system identified this and through a price increase diverted some of the cooling demand.

CONCLUSIONS REGARDING FED PERFORMANCE

As this discussion shows, it is hard to find conclusive results regarding the FED systems performance with regards to savings in energy, cost and CO₂ emissions. Due to the nature of innovative pilot projects this is not un-expected.

However, the performed analysis indicate that the FED system may potentially be able to reduce energy consumption even if this has not been shown in practice. But when it comes to reducing peak loads the potential is larger and it has also been shown in practice even if more data from actual operation is required to verify and quantify this.

The functions specified with regards to handling peak loads and ability to adapt production and consumption based on peak loads has been shown to work both through simulations and in practice with the actual system in operation.


When it comes to costs the analysis shows that the FED system may reduce costs but that the required investment costs will be roughly equivalent to the potential savings. In other words, as of now the results indicate that FED may not be cost efficient nor that it can provide financial incentives for investments. Of course, this need further study regarding price models, optimal size of the local energy market and other areas to find how to optimise the system for financial benefits.

These points indicate that if one is looking at a cost efficient way to reduce overall CO₂ emissions or peak loads there are less technically advanced and innovative ways to achieve this. At least if considering the current energy market and conditions in a Swedish context.

At this stage a key point can be identified and that is how one foresees the future energy market and what will be the main driver for developing and implementing FED type of solutions. It may be that it will not primarily be purely financial or even sustainability reasons that drives the industry towards these type of local energy markets using smart technology but rather that these solutions are required in order to handle a changing energy production mix.

7.2.3 Operation

The market trading platform has been in stable operation since January 2019. It has also shown the ability to adapt and make changes to the system through the addition of agents and actors during the test period. This means that the FED system has not been a constant entity through the operational period. The positive

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side of this is that the system’s ability to handle changes and additions to the system have been tested and it works. This is an important aspect when considering the possibility to up-scale and replicate a FED solution since it is desirable, and even necessary, that it is possible for new actors to join the market. A drawback of that the FED system has not been a constant is that it has not been possible to optimise and fully evaluate the performance of the whole system during operation.

A measure of the stability and reliability of the system is the number of bids and amount of data that the system handles. To measure this KPI 9, Creation of an energy marketplace with 10 000 business transactions during FED, was used. The achieved cumulative result to date is 248 605 business transactions, see figure 7-20.

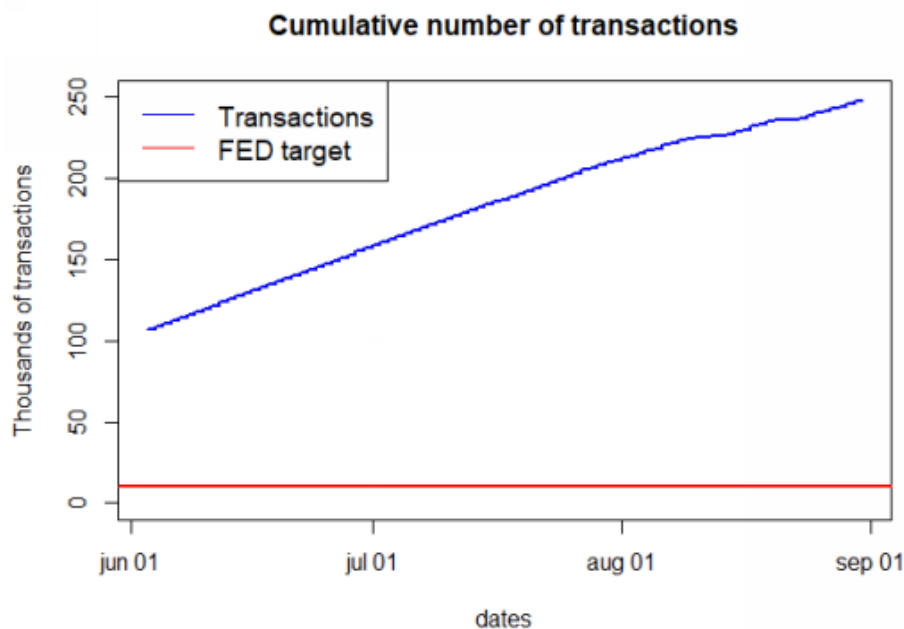




Figure 7-20 Cumulative number of transactions from June 1 st through August 2019.

This gives an indication of the amount of data being communicated as part of the FED solution. This has been a challenge in the project both for real estate owners, the development of the ICT solution and the operation of the marketplace.

DATA COMMUNICATION AND MEASUREMENTS

The different real estate partners invested within the frames of FED in a common application called WebPort in order to make the communication with the Device and Data Management system (DDM), used by Ericsson, work properly. Before FED the different real estate partners had different type of monitoring and control systems, e.g. WebFactory. Connecting the existing monitoring and control systems to the common application proved challenging and has both required more manhours than expected and been more technically complicated than might be expected. For instance there have been issues with maintaining communication between systems, performance of software gateways etc.

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One issue has been that with the amount of data required for FED the communication with the underlying assets such as digital substations, PLC's and OPC-drivers has been overloaded and hence resulted in loss of communication. The solution to this time has been to decrease cycle frequency. Another issue here is the age of almost all the equipment, some parts are around 30 years old and the technology were not prepared for this kind of development. Due to incompatible technology and not advanced technology enough, some of the components had to be replaced.

The collection of measurements have been, and still is, a big issue within this project. The gauges are many, they are sometimes old, the cables are long (sometimes up to a few kilometres long) and many applications samples the measurements simultaneously causing loss of the readings. This in combination with the poor resolution of some of the gauges, which is good enough for normal follow up on a monthly basis, causes problems with the comparison of trade within the market.

It is noted that the measurement equipment in the buildings are well suited for the normal demands in the operations, and that limitations in resolution and communication were found when stressed in the FED application. This is something that has to be accounted for when possible replications are considered.

Some of the buildings have also had some problems with the indoor temperature measurements that has been resolved by allowing the temperature to vary within a larger interval and by rearranging the position of the temperature gauges.

Worth noticing is that simple things as firewalls within the companies' IT systems might cause major problems e.g. by blocking needed external sources of information such as weather forecasts etc.



These aspects are an important lesson learned from the project, that even with today's available smart technology there are many challenges when looking to connecting different systems. Lack of standardisation, measurement equipment resolution and requirement for handling, communicating and storing large amount of data are issues that need to be resolved to lower the threshold for FED type solutions to be implemented.

ICT SOLUTION

With the setup of the ICT platform and marketplace that has been constructed it has been possible to have a stable operation for almost a year and add new agents as they are ready to be implemented. The FED-system have shown a strong stability despite these disturbances, which is a major advantage in a real situation where new actors would join in a local market at different stages. The system has also shown good scalability.

Ideally, the central system for the ICT solution is supposed to only contain the energy market, as well as some general service providers providing forecasts for things such as outdoor temperature and solar, making it relatively lightweight. Even the most resource intensive process that calculates and optimizes the distribution of energy production and consumption once an hour does so in a couple of milliseconds for the entire Chalmers campus, making scaling reasonable.

Every building owner is then responsible for hosting their own agents on their own servers for their own buildings. This ensures that the central system is not overloaded with work and can focus its work on the resource intensive optimisation task (if scaled to something larger than a campus). That means of course that building owners and other market actors must in the general case find a way to host and manage their own agents (including costs). It might be a big obstacle for some potential actors, and solutions to that has

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to be considered in a general replication situation. But it should be noted that to ensure scalability for the FED solution it may be necessary to require each market actor to host their software agent.

For practical purposes, in this project all agents run together with the central system. This creates a couple of processing and latency bottlenecks. Most obviously, running 50+ agents on the central system causes a large competition for resources amongst all processes. For the current scale this is fine, as the system facilitates scalability with microservices in a cloud-based environment using docker and kubernetes and all the agents are written by the same partner (Ericsson). Machines can be added to or removed from the cluster if more or fewer agents need to be accommodated, but if scaled up to an entire city or country it would be unreasonable for the operators of the energy market to shoulder the entire cost of hosting all agents on their system.

In addition, having all agents on the central system may constitute a risk for the system reliability and stability. A badly performing agent might negatively impact and potentially bring down the entire cluster if running on the central system. Another aspect of reliability is how the system handles issues, such as missing forecasts, faulty measurement data or loses contact with the physical asset.

Another problem is that many of these agents need information from meters and appliances within their respective buildings in order to create their bids. This necessitates the usage of Ericsson’s Device and Data Management system (DDM) which is a centralised system that keeps track of and automatically updates various relevant values to be used by agents. The DDM is currently the biggest source of latency within the system as some of the agents require up to a 100 different values to be continuously updated every five minutes for them to base their bids upon. If all agents, as previously mentioned, were hosted by the building owners the communication between agent and building meters would be handled by them as well, removing the need for a centralised data management system.



These findings show that there are many advantages with having each market participant hosting their own agent on their servers. It may also be required to spread out costs, avoid issues with capacity and latency for the central system. In particular when considering up-scaling and including many more actors on the market it may not be practically feasible to consider any other solution. However, it is important to consider what requirements this puts on market actors, both technically and financially.

In order to ease the development of agents Ericsson have created a number of utilities which handle most of the parts which agents commonly need. This includes the creation of bids and dependencies, communication with the market and communication with their underlying assets. By optimising these utilities it is possible to improve and update all the agents at once, thus avoiding having to implement the same solution multiple times.

7.2.4 Market design evaluation

The energy market design and implementation is itself one of the major results of the FED project. The design of the market is described in chapter 4.4. Section 7.2.4 includes an evaluation and discussion of the market design. This is taken from an article, M. Brolin, H. Pihl, “Design of a local energy market with multiple energy carriers”, accepted for publication in International Journal of Electrical Power and Energy Systems, November 2019.

There are numerous aspects that needs to be analysed and taken into consideration. Below follows a brief discussion on a few key aspects related to integrated local energy markets as described in this report.

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THE INDIVISIBILITY ISSUE

The market optimisation problem is linear and no integer variables are introduced. This means that there is no possibility for agents to submit indivisible bids, i.e. bids that should be either fully accepted or not accepted at all. Indivisible bids could in some circumstances be a useful feature for some agents. For example, a producer may have a minimum-load requirement such that it has to either be turned off or operate above some minimum level. If indivisible bids were allowed, the agent could submit an indivisible bid for this minimum-load energy and let the market decide whether it should be off or operating.

However, indivisibilities can cause the shadow prices from the power balance constraints to no longer provide appropriate market clearing prices. In fact, when indivisibilities are present, a uniform market clearing price may not exist. There are several options for dealing with this issue. The approach chosen in FED is to simply not allow for indivisible bids and let the agents manage their indivisibilities using other tools, such price forecasting and planning models. Alternatively, it could submit a divisible bid and, in the unlikely event that it happens to be marginal, take the risk of ending up in an imbalance position. This option was chosen in order to not further increase the complexity of the market design.

It can be discussed what is preferable; an increased complexity of the market clearing function or having a more complex decision making function of the agents. Other options have their own drawbacks such as less beneficial from an optimisation point of view or creating the possibility for market manipulation.

ROLLING HORIZON AND FINANCIAL SETTLEMENT



In the proposed market design, each market clearing returns market results for the full trading horizon. However, only the results for the first hour in the horizon, the binding hour, is used for financial settlement. Only using the binding hour for financial settlement means that market participants may not have financial incentives to place truthful bids for hours further out in the market horizon.

This could, at least partially, be alleviated if all time-periods were financially settled and re-settled for every market clearing. A drawback with such a settlement approach is that it would make the furthest-out time-period financially very important, which would increase market participant risk. It would also make it much more difficult for market participants to understand the final settlement amounts.

MULTIPLE ENERGY CARRIERS AND FLEXIBILITY INSTRUMENTS

In order to facilitate the integration of different energy carriers, the proposed market design clears multiple energy carriers simultaneously through one common optimisation. This increases the possibility to use synergies and thereby an efficient use of resources. The proposed model includes different bid dependency options that the agents can apply in order to provide the market with flexibility, but leaves for the centralised market clearing to decide on how to dispatch such assets in an optimal way. The implemented instruments are based on logical relations between bids, offering a wide range of flexibility options (e.g. load shifts between hours and the shift of energy carrier), but also the possibility to impose restrictions on the independence of operation of equipment coupled to different energy systems (e.g. for heat pumps and CHPs).

Even though the proposed flexibility instruments provide a vast list of options and possibilities, there are limitations in what they can represent. For example, since agents cannot submit indivisible bids, the possibility for a market participant to completely switch between electricity and DH cannot be ensured, i.e. it cannot be ensured that only one of these options exclusively will be cleared. Another limitation is the

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difficulty to construct bids for energy storage that takes full advantage of the flexibility offered by such assets. Although it is possible to construct bids and bid dependencies that represent a specific charge and discharge cycle, it is difficult to fully capture all possibilities and constraints of a typical energy storage. Accurately capturing all possible charge and discharge possibilities over a trading horizon would require a very large number of bids and bid dependencies. Further, the available capacity for hours further out in the horizon depends on the amount cleared in prior hours. However, it is not possible to condition the bids in one hour on the outcomes of another hour within the same market clearing.

MARKET COMPLEXITY AND TRANSPARENCY

A matter already touched upon when discussing indivisibility is that with increased functionality of the market clearing function comes an increased complexity and possibly challenges in interpretation of market clearing results. Findings in the FED project indicates that even though it is limited in size in terms of agents, time steps and bids, the results from the market clearing still provide challenges in the interpretation of the optimisation results.

An implementation encompassing also network representations in order to reflect congestion in different energy carrier grids, will increase the complexity even further. The complexity in market design can have negative effects on transparency and intuitive understanding of the market and the resulting prices, which can lead to a lower trust for the market clearing function and hence constitute a barrier for implementation.

COMPATIBILITY WITH EXISTING MARKET STRUCTURES

An important question regarding the possibility to implement local energy markets is to what extent they are compatible with existing wholesale markets and other regulatory frameworks that govern energy trading. This complex topic requires a more thorough discussion than what may be included within this report. But two aspects are touched upon here.



First, the intention of the proposed market design is that it should be compatible with European-style day-ahead and intraday wholesale electricity markets in the sense that exchanges between the local market and the wholesale market can be handled by the retail agent. Further that the time-period length and market execution timing of the local market can be adapted to align with overlaying wholesale markets.

Second, in jurisdictions (such as in much of Europe) where consumers have the right to choose their electricity supplier, it may be difficult to ensure that all consumers and producers within a local system are reflected in the local market. This could be a barrier for the implementation of the proposed local energy market since it requires a representation of anticipated energy flows in the network models. If some consumers and produces opt out of participating in the market, this representation may be more difficult to achieve.

MARKET LIQUIDITY AND MANIPULATION

Local energy markets are likely to include a limited number of actors and market participants, implying that individual bids may have a substantial impact on market prices. This can reduce incentives for entry of new market participants since the market can be considered unstable and unpredictable, making it difficult to hedge and respond to changes in market conditions.

Another possible disadvantage of the markets such as FED is the exposure to market manipulation and market power. The exercise of market power leads to reduced economic efficiency, and hence it is in the

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interest of the market operator to hamper such behaviour. This can be done by e.g. designing the market so that it becomes less sensitive to strategic behaviour. How to achieve this has not been part of the FED project but it can be noted that there might exist conflicts of interest in this respect. An example can be the use of nodal marginal pricing as a pricing mechanism. As a consequence, the pricing might become sensitive to manipulation, but on the other hand the marginal pricing option creates incentives for agents to be active and to provide flexibility. Hence, the same mechanism facilitating an efficient operation of the system if no market power is being exercised also provides possibilities to execute such behaviour.



CONCLUSIONS FOR THE MARKET DESIGN

Some conclusions that can be drawn from this evaluation of the FED optimisation based market clearing design are:

- Applying an optimisation-based approach for formulation of the market clearing allows for the implementation of various functionality, such as bid dependencies, which otherwise would have proven challenging.
- The possibility to apply logical dependencies between bids allows for a wide range of functionality for representing flexibility as well as restrictions in the bidding process for market participants. Bid dependencies can be applied to represent various technical characteristics of the underlying physical assets.
- Incorporating multiple energy carriers in the market clearing can potentially lead to synergies and to an increased efficiency in the use of existing resources.
- Even for relatively small market clearing optimization problems, challenges arise in the interpretation of results in terms of cleared market prices and bid quantities. An increased complexity in the market design could lead to difficulties for market participants to interpret market results.

Furthermore, as discussed above, there are issues relating to the market design and how this should be developed in order to provide a solution that is attractive for potential market actors and that have solved the challenges regarding risks for market manipulation and strategic behaviour. These are important steps in order to replicate and develop FED into a commercial solution.

The FED market design is complex, as discussed above this follows from having several energy carriers within one common market and is necessary to provide the requested flexibility and possibility to optimise the local energy system. This then becomes a challenge to balance the required complexity with creating a market that is also sufficiently transparent, robust and simple that it can attract stakeholders to join and trust the market.

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7.3 Testbed

One aspect of the FED project is that it has functioned as a successful testbed and that this has initiated a number of research projects, innovative R&D projects, initiatives to replicate FED and in general spreading know-how and experiences both within Sweden and internationally.

One part of this has also been the co-operation within the partner group itself, this is in itself a result and both a success factor for the project and something that has provided valuable knowledge and experience in the participating organisations.

These were measured and evaluated through KPI 11, 12 and 14, a summary of the results from these are shown in table 7-3 below.



Table 7-3 Summary of KPI results for implementation of FED solutions, dissemination and lobbying activities.

KPI no.	Title	Target value	FED result
11	Implementation of FED solutions within Göteborg or elsewhere	10 FED replications	23 FED replications
12	Dissemination of FED project with articles, presentations, etc.	3 presentations at research conferences 100 delegation visits to FED	3 presentations 37 delegation visits 86 conferences, seminars, meeting and workshops 133 news articles
14	Lobbying activities for local energy community developments	18 activities	30 activities



In table 7-4 below a number of research projects that are connected to FED are listed. These range from large EU projects to local innovation projects and master thesis projects. All these projects are answering to some or several FED – related challenges.

Table 7-4 Examples of research projects initiated answering to FED-related challenges.

Project name	Type of project	Owner
IRIS – smart cities	Horizon 2020 EU funded	City of Utrecht
ACCESS	Interreg North Sea EU funded	VITO
Forsåker	Local development of a new sustainable urban area	MölnDala Fastigheter AB
Innovative Building Management System	Academic research project at Chalmers University of Technology	Chalmers University of Technology Göteborg Energi
USB-C for smart buildings	Innovative start-up	Ochno

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Project name	Type of project	Owner
Celsius Initiative – smart cities	Climate-KIC and Swedish Energy Agency funded project	JSP
Phase Change Material – Cooling energy storage	Innovation company, product development	Rubitherm
Replication study of FED project to a location within the Netherlands	Master level internship report	Sandra Greven JSP
Replication of local energy management systems to an urban area	Master thesis, Chalmers University of Technology	Nima Mirzaei Alavijeh Cristina Alemany Benayas
Taking Charge	Local innovation project	Ferroamp
EnergiVision - INU	Local innovation project	INU
Flexigrid	H2020 EU funded project	IMCG

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7.4 Lessons learned

This chapter summarises lessons learned by the FED partners. The first part focuses on evaluating the technical solution, identifying the biggest challenges, any technical limitations and how well suited today's systems and solutions are for implementing FED type solution. The second part includes a look ahead with focus on the need for further development and what is needed to make FED a feasible commercial solution.

EVALUATION OF THE TECHNICAL SOLUTION AND MAIN CHALLENGES

Main lessons learned regarding the technical solution and project challenges:

- Lack of documentation and/or visualisation of the technical systems (buildings / production units) made it difficult for other parties to understand the function and interaction of the local production units and consumption side of the system.
 - Note: A finding from the project was that this project required that several parties with little experience and knowledge of technical installations in energy systems and buildings needed to understand these in order to develop the simulation model and the market itself, including agents, bids and so forth. The available documentation for technical installations and production units are not suited for this type of information and this made the work more difficult. Nor is there typically any visualisation made of the technical systems that could help to provide an understanding of how the systems function and are connected.
- Several of the investments in the project were funded and controlled by projects other than FED. This means that schedule and execution of these were not within the control of FED. This in turn, led to delays and impact on project schedule and / or use of resources.
 - Note: In future replication projects one should strive to have control of as large part of all included investments and installation within the demonstration / pilot project as practically possible.
- Large number of participants in the project from many different disciplines and industries.
 - Note: The nature of the project requires the participation of many partners and a wide variety of know how and experience. However, many parties from various industries and backgrounds require a high level of communication and mutual learning at the beginning of a cooperation like the FED project. Meeting structures and other tools for much information exchange is required. On the other hand a lessons learned is also that a key success factor for the project was that it included such a variety of know-how and technical expertise. Without this multi-discipline collaboration FED would not have been possible.
- New technologies and / or requirements means that there is a lack of experience and know how both at real estate owners, within the building industry in general and even at manufacturers of the equipment itself
 - Note: Solar panels are existing technology that is getting increasingly well established. But this project showed that there is a lack of knowledge and in-depth technical understanding of this technology from both the suppliers and manufacturers. The suppliers could not

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deliver such functions as the FED project required, i.e. ability to control output and reactive power from the solar panels.

- State of the art technology used today in new production is quite well suited for the requirements that FED type of solutions put on the technical installations. For older, existing buildings this is seen as a major challenge.
- Measurement equipment and standards used today are not well adapted to the requirements of a FED system. Resolution and amount of data to be transmitted for heating and cooling systems are designed to ensure correct information for energy typically on a monthly basis, not to provide hourly readings for power.
 - Note: Measurement equipment and data collection has been a major issue and was identified as the main technical challenge in the project. The standard measurement and technology and method used today in heating and cooling systems are not suited for the requirements of a FED system (hourly measurements, including instantaneous power). Even if real estate owners have overlaying systems for collecting data and measurements these are not normally set up to handle large amount of data at an hourly level.

Additionally, real estate owners typically have their own system for how to designate buildings, sensors, systems and may also use a single sensor to measure the energy for several buildings or parts thereof. All this means that it is not straightforward to simply communicate measured data to an overlaying system or market such as FED. Work is required to translate this data to ensure that the overlaying system not only get a set of measurements but also understands what this data signifies, i.e. what building, what sensor and so on.

A lesson learned regarding commissioning and optimisation of the operation of production and storage units within the FED system is that this is time consuming. When planning for replication of a FED type solution one should take into account that this is a complex issue and if not given sufficient time may lead to delays and/or loss of performance.



A lesson learned from FED is that any replication of these type of solutions need to address this issue and find a way to simplify and work towards standardisation to ensure that data collection is made easier. When it comes to measurement there is a need for development and to set up new requirements for procurement.

Of the above findings two were identified as most important: measurement equipment and data collection, and lack of documentation / visualisation that could help with the understanding of the technical systems.

FUTURE DEVELOPMENT

Main lessons learned regarding the need for further development required to make FED (or a FED like) solution feasible:



- The market design is complex and would benefit from being simplified. This would also increase transparency.
 - Note: The developed market, including bids and prognosis, was advanced, which in turn increased the required complexity of the software agents and IoT platform. A simpler

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model that reduced the complexity is desirable. An estimate is that it should be possible to reduce complexity without significantly reducing performance.

- There is a need for further standardisation on several levels: communication with building automation control systems to external part, set up and function of software agents, standards for measurement equipment.
 - Note: To lower the threshold for implementing solutions such as FED it is necessary to standardise. This can take place on several levels and applications. One area identified in this project is the interface between building and marketplace. Today there are several types of protocols for communication, SCADA systems in buildings and internal automation and control systems for technical systems.
- More demonstration projects are needed, in particular for areas closer to a typical urban area.
- The cost for connecting to the FED market must be minimised, which includes cost for connecting to the marketplace, development of agent and investments for measurement and control.
- For future replication one should look for available, off-the-shelf solutions and technologies for installation in the buildings to provide the required flexibility at a low cost. This is to lower the required investment and simplify the interface and connection of a building to the market place.
- FED need to be further developed in terms of setting up a business model, clarifying the customer, potential business value for individual market actors and turning FED into a product.
- Knowledge regarding FED type solutions (local energy market and IoT solutions) need to be more widely spread among the people in the industry working with building automation and control systems.
- Further work is required with the social acceptance to get individual real estate owners interested and seeing the value both to invest and to be prepared to give control of their building or production unit to an external part. An important aspect in this is the financial part, to identify the associated costs, risks and opportunities for the individual potential market actor but also for the system as a whole.

Work with knowledge sharing and social acceptance is required in order to successfully implement these types of solutions. This is valid both for organisations such as real estate owners, energy companies and the building industry in general and on an individual level for householders and people working within the building industry.

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8 CONCLUSIONS

There are today many projects, including research, that deal with issues of local energy markets, smart IoT solutions, local energy production and other subjects related to FED. The FED project has taken a big step forward within this field and gone from theory to practice. In this project an actual digital market was built and operate on a local energy market encompassing more than 50 buildings and production units. In addition, this local energy market is connected to and can provide services to the external networks, in this case municipal district heating and electricity grids.

To manage this and provide a functioning local energy market is a major achievement. This pilot project provides valuable know how and experience to the field both within the participating organisations, to the industry, academy and by disseminating and sharing this knowledge it may help this entire field of development take the next step.



Some main conclusions for the energy market:

- FED has delivered a common marketplace with three energy carriers
- The ICT solution provided a stable, robust and scalable marketplace with the ability to add, change and adapt market actors whilst in operation
- The FED system has shown several functions providing benefits responding to the needs of the future energy market: handling larger share of renewable energy production, reducing peak loads, handling issues with power shortage and grid stability, including multiple energy carriers and local waste heat recovery
- Results from simulations and actual operation indicate that the system can reduce peak loads and overall CO₂ emissions. Simulations show that the potential reduction of these can be in the order of magnitude of 20 % compared to a business-as-usual scenario.

FED as of today may not be a cost-efficient way to reduce CO₂ emissions or energy consumption. But the project has shown that it might be one possible solution to handle issues for a future energy market with an increasingly volatile energy production, need for increased flexibility and improved use of energy storage.

In order to further develop FED and replicate this solution some key findings from the project are:

- Measurement, data collection and communication between buildings, production units and the digital marketplace are vital for the technical implementation of solutions such as FED. Preferably, the industry should move towards a higher degree of standardisation in order to simplify this and lower the threshold.
- There is a need for more demonstration projects to increase and share knowledge of local energy market.
- There must be a well-developed business model with clear definitions of customer and owner / operator of the marketplace.

 EUROPEAN UNION <small>European Regional Development Fund</small>		FED – Fossil Free Energy Districts
		Funding scheme: UIA – Urban Innovative Actions
		UIA 01-209
		Project period: 2016-11-01 – 2019-10-31

- The marketplace and design need to be developed to ensure trust and transparency, this includes having solutions for price models, handling and preventing unwanted strategic market behaviour and generally steering the market actors towards the desired behaviour.
- There is a need to update and make changes to regulations and policies regarding local energy markets. Currently the Swedish regulations severely limits the possibility to trade with electricity within a local market.
- Social acceptance is a prerequisite for a successful implementation. This means that any project looking to replicate FED must include working with social acceptance on several levels, for organisations, within the industry, policy makers, individual users and other stake holders.

A large part of the FED project has also been to work with strategy for replication, this work has included studies to identify need for changes to regulations, technological barriers, roles and other social aspects but also providing recommendations for policy changes. This work has also included dissemination of results, lobbying activities and participating in more than 85 conferences, seminars, workshops, meetings etc. as well as receiving 37 delegation visits.

In addition to the technical parts and the replicability analyses of the project, FED has functioned as a testbed and through this project more than 15 R & D projects have been initiated responding to the challenges of local energy markets. These projects range from academic research, master thesis work to innovative start up projects and large EU funded projects.

As part of the FED project more than 10 companies have been involved to test and develop their products and services. This includes adding functions and developing existing products and solutions but also innovative technology such as PCM energy storage. Last, but not least, a number of initiatives looking to replicate FED type solutions have been initiated.