D2.3: Report on the Flexibility Market

+CityxChange | Work Package 2, Task 2.6

Final delivery date: 31-12-2019

Deliverable version	v.06
Dissemination level	Public
Responsible Author	Stian B. Hackett (TrønderEnergi)
Contributors/authors	Stian B. Hackett, Bernhard Kvaal, Magnus Fure Runnerstrøm, Hanne Høie Grøttum, Nina Økstad (TrønderEnergi), Klaus Livik, Stein Danielsen (Powel), Stephen Wright, L.M. van Vuuren, Dudley Stewart, Mladen Antolic (MPOWER), Stian Backe, Güray Kara, Pedro Crespo del Granado (NTNU), Morten Einar Nyrø Fossum (Statkraft Varme), Marius Lauvland, Hans Erik Frøyen (ABB), Joakim Helde (ABG), Tor Rune Skoglund, Mamdouh Eljueidi (FourC)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 824260.

Document Information

Project Acronym	+CityxChange
Project Title	Positive City ExChange
Project Coordinator	Annemie Wyckmans, Norwegian University of Science and Technology
Project Duration	1 November 2018-31 October 2023
Deliverable Number	D2.3: Report on the Flexibility Market
Dissemination Level	PU-Public
License	CC-BY4.0 Creative Commons Attribution, except where otherwise noted. https://creativecommons.org/licenses/by/4.0/
Status	Complete
Due Date	31-12-2019
Work Package	WP2 – The Common Energy Market
Lead Beneficiary	TE
Contributing Beneficiaries	NTNU, TK, POW, ABB, ABG, SV, 4C, MPOWER

Revision History

Date	Version	Author	Substantive changes made
25.07.2019	v.01	Stian B. Hackett (TE)	Initial version built from working documents
30.08.2019	v.02	Stian B. Hackett (TE)	Version for initial review
11.11.2019	v.03	Stian B. Hackett (TE)	Version before chapter rearrangement
15.11.2019	v.04	Stian B. Hackett (TE)	Version for second review. Reorganised chapters. Added last part of Chapter 4, especially 4.5. Added Chapter 5.
19.12.2019	v.05	Stian B. Hackett (TE)	Various rewriting. Cut parts of Chapter 5, added information table about Fellow Cities (5.4). Submitted version.
31.12.2019	v.06	Stian B. Hackett (TE)	Fixed minor errors, simplified/cut parts of chapters 3 and 5, and related text

Table of Contents

List of acronyms

BRP	Balancing Responsible Party
CGS	Community Grid System
CSO	Community System Operator
DER	Distributed Energy Resources
DNO	Distribution Network Operator
DSO	Distribution System Operator
LEM	Local Energy Market
LFM	Local Flexibility Market
LMO	Local Market Operator
LV	Low voltage
NZEB	Nearly zero-energy building
PEB/PED	Positive Energy Block/District
RES	Renewable Energy Sources
TSO	Transmission System Operator
V2G	Vehicle-to-grid

Executive Summary

This report, deliverable D2.3 of the +CityxChange project Task 2.6, describes a framework for how a local flexibility market (LFM) can be designed. In the context of the Positive Energy Blocks to be created within +CityxChange, LFMs provide market mechanisms to prevent grid congestion and aid with the integration of renewables. Because technological preconditions and objectives for LFMs can vary between locations, the +CityxChange project calls for a general design framework (tool) for how to proceed when considering an LFM in a given location. The report describes our approach to the design framework and applies it to +CityxChange lighthouse cities Trondheim (Norway) and Limerick (Ireland) as examples. The same general method may be used by other cities and locations.

The incentives for trade in LFMs may be implemented by distribution network operators (DNOs) or by local market operators (LMOs). As DNOs in Europe develop into Distribution System Operators (DSOs) they can become both market platform operators and/or buyers of flexibility in LFMs. While LMOs will not have system operation responsibilities, they may, through LFMs, provide services that are valuable to system operators and to those who wish to connect production or consumption to the grid.

The report makes a distinction between different forms of flexibility trading. First, LFM participants may sell flexibility services to an institution, like a DSO, LMO or aggregator. This principle is fairly well established. Second, in line with +CityxChange objectives, we also describe how participants could trade with each other, for purposes that are similar to the objectives of grid tariffs. This is referred to in the report as internal trading, and seems less explored until now. Internal trading generally requires that a DNO/DSO or LMO introduces new, special incentives, explicitly as or akin to special grid tariffs.

The LFM is envisaged to be built around a trading platform, which will be further developed in +CityxChange Tasks 2.3 and 2.5 (deliverables D2.6 and D2.7). The report describes several options for market operation systems, the price-setting mechanisms in the platform. We describe options both for internal trading and trading between flexibility providers and institutions. We identify several challenges with the option of flexibility activation pricing, where flexibility providers can be paid to shift their consumption or production away from a reference point. Without appropriate countermeasures, flexibility activation pricing risks that flexibility providers (including automated systems) are incentivised to shift the reference point itself, in the "wrong" direction. Safeguards against this possibility are therefore given much attention. However, we recommend that further research, detailing, and verification of these safeguards is continued in subsequent tasks – especially Tasks 2.3, 2.5, 4.10, and 5.10.

In applying the market design framework in this report to the +CityxChange pilots in Trondheim and Limerick, we find that several key recommendations tend to recur in both. Our hypothesis is that this also largely applies to the +CityxChange Fellow Cities. However, there are also meaningful differences, mainly linked to long-lived factors such as natural resources and physical infrastructure. As the energy system in Norway in many ways is an

outlier in the European context, the +CityxChange Fellow Cities may find more familiarity in the Limerick case. However, the solutions tested in Trondheim may still be relevant.

One expected difference between the LFM design approaches in the Trondheim and Limerick test areas lies in how Limerick aims to test a solution in which the local market's net position (production minus consumption) cannot be positive. This will allow more production capacity to be connected. In the Trondheim test areas, however, we do not expect the LFM design to include this requirement. This will make it easier to achieve the +CityxChange goal of Positive Energy Blocks with cumulative energy surpluses over a year. The details of the LFM design in the two lighthouse cities will continue in +CityxChange tasks 2.3, 2.5, 4.10 and 5.10, building on the principles in this report. However, much may also depend on regulatory dispensations, the feasibility of which will be tested in Tasks 4.4. and 5.4.

1 Introduction

One of the aims of the +CityxChange project is to develop local energy- and flexibility markets that can complement and help to enable Positive Energy Blocks (PEBs) (+CityxChange, 2018a; +CityxChange, 2018b; Ahlers, Driscoll, Wibe, & Wyckmans, 2019).[1] This report, deliverable D2.3 in +CityxChange, outlines a design framework for what e.g. Minniti, Haque, Nguyen, & Pemen (2018) have called "a local flexibility market (LFM)" (p.1).[2] In D2.3, we describe LFMs as markets that enable various stakeholders to purchase flexibility from within a given area. In this context, buying flexibility means paying another party to shift their pattern of energy production or consumption, either in time or between energy carriers (e.g. between gas and electricity). The incentive to buy local flexibility comes from systems that give various actors a monetary stake in the patterns of energy consumption and production of the actors in the LFM. These actors are in many cases prosumers. In this report we use the USEF (2016) framework definition of prosumers, in which they encompass not only consumers with some self-generation but also flexible consumers.

As the +CityxChange project also calls for close integration between LFMs and "a local energy market" (+CityxChange, 2018b, p.92), (LEM)[3] the report explores the concept of an LFM that also incorporates local energy trading. In our context, local energy trading means that within a local market, special incentives or circumstances make retail energy prices potentially different from the "outside" system. Such a local price can reflect local grid constraints and potentially network losses more accurately than the "outside" price, and may also reflect particular preferences for locally produced energy. However, a LEM is not interpreted here as the same as a wholesale price zone or node.

Several stakeholders may be interested in buying the flexibility of the LFM participants. In the context of this report, some of these are considered "external" while others are "local". External buyers are those who wish to employ flexible assets to solve system-wide problems (especially electric power balancing). In electric power markets, this could for example be aggregators serving the balancing markets of transmission system operators (TSOs). "Local" buyers are mainly incentivised to solve local problems (especially local grid congestion), and will include the distribution system operator (DSO) and possibly the LFM participants themselves if particular incentives are introduced. In this report we focus primarily on the interaction between the local buyers and local sellers, as the coordination between TSOs, Balancing Responsible Parties (BRPs), and DSOs is described extensively in other literature (see e.g. CEDEC, EDSO for Smart Grids, Eurelectric, & GEODE (2018), Eurelectric (2014), Gerard, Puente, & Six (2018), and USEF (2018)).

The report explores how the prevention of local congestion in part can be addressed by particular grid tariffs or equivalent incentives, combined with an opportunity for LFM

[1] See also the European Commission/SETIS (2018). As described in Ahlers et al. (2019): "The initial definition of a PEB is as a collection of buildings in close proximity that have a averaged yearly positive energy balance between them" (p.2).
[2] Hereafter used without quotation.
[3] See footnote 2.

participants to trade flexibility with each other to minimise their costs of adaptation. This can reduce peaks in both net consumption and net production, and stimulate long-term adaptation and investments in flexibility that may delay the need for grid expansion and allow more local generation to be connected. In potentially congested situations, however, the local system operator may need to use contracted local flexibility for system services. By including system services as a product in the LFM, the principles outlined in this report also cover the balancing of a microgrid.

The report begins by explaining in more detail the objectives of local markets (Chapter 2) and the potential of local production assets and flexible consumption assets as well as storage (Chapter 3). Chapter 4 answers the call in +CityxChange (2018a) for a "flexibility market design tool" (p.25)[4] and a "market operation system" (p.25).[5] The market design tool is interpreted as a framework for LFM design that is adaptable to different European cities. In line with the call, this includes a relationship chart that maps information ("data and analytics" (+CityxChange, 2018a, p.25)) about local conditions to likely recommendations for LFM design. Furthermore, several options for the design of a market operation system, the price-setting mechanisms in LEMs and LFMs, are described. In Chapter 5, we discuss how the principles described in this report are likely to apply to European cities. As examples, we outline in more detail how the design principles point to directions for LFMs in the pilot projects in Trondheim and Limerick, the two +CityxChange lighthouse cities. The subsection for Limerick (5.2) also describes how the principles in this report apply to the concepts of *Community Grid Systems* and *Community System Operators (CSOs),* building on earlier work by MPOWER and MEGA (see Stewart (2015)). Continued development of these concepts is scheduled for +CityxChange Task 2.3 (+CityxChange, 2018a).

[4] See footnote 2.
[5] See footnote 2.

2 Local flexibility and local markets

Flexibility can be defined broadly, but in this report the term is limited to flexibility in time and in the type of energy carrier, both for production and consumption. These forms of flexibility enable solutions to existing and future problems in the energy system. In Section 2.1, the solutions to such problems are listed as the core motivations of using local flexibility, whether through LFMs or through other incentive structures (e.g. grid tariffs). However, local flexibility can also have other benefits, which may not in themselves be considered important enough to introduce incentives for local flexibility but should still be accounted for when considering such solutions.

Local flexibility is a generic concept that is broader than a local flexibility *market*. In Section 2.2. the concept of *Local Markets,* which covers both Local Energy Markets (LEM) and Local Flexibility Markets (LFM) is described.

2.1. Motivations for and benefits of local flexibility

2.1.1. Core motivations

The core motivations for using local flexibility are mostly related to what Minniti et al. (2018) call "Grid-oriented services" (p.5).[6] These mainly include the avoidance of congestion and reverse power flows in the electric grid.[7] Furthermore, local flexibility operating through an LFM could be integrated with the needs of the wider electricity system (Minniti et al., 2018).

2.1.1.1. Regulating the net position of a local area

For the purpose of LFM design in this report, grid-oriented services can often be conceptualised as the general goal of keeping the energy balance or net position of a local area within certain grid limits. The net position is the net balance of any collection of producers and consumers, in other words their total production minus their total consumption at a given time.[8] Figure 2.1 illustrates how local flexibility can be used to "compress" the net position over a 24-hour period. This keeps it away from limits defined by the state of the network.

[6] See footnote 2.
[7] While this report focuses mainly on the electric grid, the problem of congestion also may apply to other energy carriers.
[8] The same principle (production minus consumption) can apply at any scale.

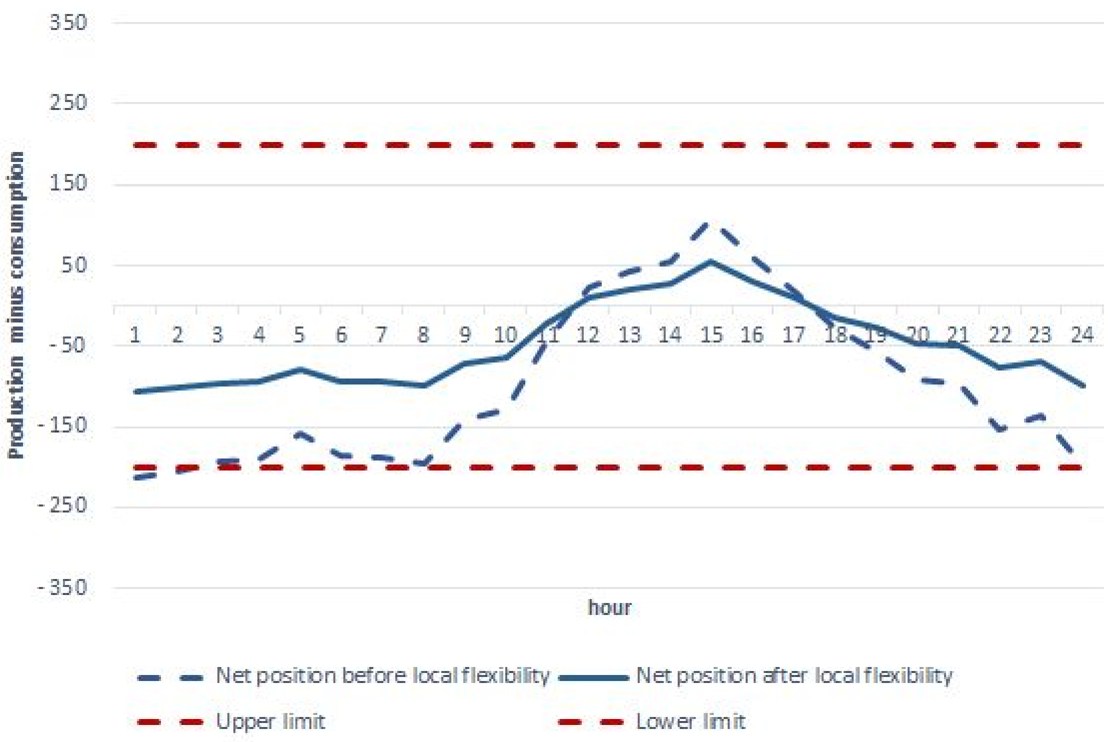

Figure 2.1. Generic example of how local flexibility can compress the net position of a local area, keeping it away from critical or pre-set network limits.

The limits in Figure 2.1, which in some cases may be zero,[9] can represent actual physical limits like the maximum capacity at a point in the network. However, they could also be defined as narrower, pre-set limits that will trigger monetary incentives when crossed. This can incentivize flexible behaviour even when the net position is safely within the physical limits. In this case, the likely purposes include reducing the probability of actual spikes, stimulating investments in flexible equipment and infrastructure over time, and potentially reducing grid losses. In this context, it is therefore useful to distinguish between what USEF (2018) call "*congestion management*" (p.7) and "*grid capacity management*" (p.7).[10] In this report, we interpret congestion management as the prevention of actual congestion as it is about to happen, while grid capacity management aims to reduce the chance of future congestion and thereby potentially delay or avoid grid upgrades. Grid tariffs can be an example, especially if they target peak loads. However, individual grid tariffs do not necessarily target the collective net position of an area. Chapter 4 in this report discusses incentives that more accurately target the collective net position, including trading between prosumers (and potentially consumers)[11] in the LFM area.

[9] For example, the electricity net position of a microgrid would have to be zero at all times when it is in islanding mode.
[10] Hereafter, these two terms are used without a quotation each time. See also USEF (2016, p.24)
[11] Depending on whether the LFM is open to regular consumers or only prosumers.

2.1.1.2. Coordination with system-wide balancing

Keeping the net position of a particular part of the grid within certain limits is mainly in the interest and domain of DNOs/DSOs, the institutions that operate distribution grids.[12] However, local flexibility resources can be expected to also respond to economic signals that seek to balance the "wider" electricity market. They may respond flexibly to varying spot prices, and may be contracted by aggregators that serve BRPs and TSOs. The coordination between potentially conflicting "local" and "external" needs is a challenge, but is not dealt with extensively in this report due to its comprehensive treatment elsewhere (CEDEC et al., 2018; Eurelectric, 2014; Gerard et al., 2018; USEF, 2018).

2.1.2. Additional benefits

In addition to the core motivations, local flexibility may also have other less decisive though still important benefits. In the following, the primary additional benefits are presented.

1) Reduction of overall energy losses. Using flexibility to more frequently match local production with local consumption can potentially reduce grid losses. However, it is not always the case that this reduces system-wide losses, and this potential benefit has to be considered case by case. Moreover, differences in marginal losses can be captured through overall tariff design (Pérez-Arriaga et al., 2016), which can capture such effects in the overall system as well as in a particular area. Hence, potential grid loss savings from the actions of a particular area should be considered in the context of the signals from the overall tariff system (current or planned).

2) Contributing to energy efficiency. Placing a value on local flexibility can enable the discovery of potentials for energy saving, which is particularly relevant to the +CityxChange project objectives (see +CityxChange (2018a, 2018b); Ahlers et al., (2019)). In particular, incentives for flexibility increase the value of building control systems, which may entail discoveries of sources of energy waste.

3) Increased access to local energy. Consumers may have a preference for locally produced energy, beyond its value to the grid. Operationally, this means that local customers may be willing to pay more for locally produced energy than the common price in the price zone or node to which they belong. A plausible reason for this is that locally produced energy often means solar energy or another form of renewable energy source (RES), for which the customer may have a preference. Local flexibility allows energy users to shift their consumption to times when such local production is available. In a European context this also requires, however, that the customer does not find the existing Guarantees of Origin (GO) scheme sufficiently credible.

[12] A DSO is a DNO with extended capabilities for system operation.

2.2. Local Markets

One of the tools for making use of existing flexibility and to stimulate investment in more flexible assets is the deployment of local markets. This term includes, in our context, Local Flexibility Markets and Local Energy Markets. As LFMs and LEMs potentially draw on the same local resources and may be implemented on the same trading platforms (as in the +CityxChange pilots in Trondheim and Limerick) we expect that these markets may be closely integrated in practice. In the context of LFMs as described in this report, it may be more accurate to think about LFMs and LEMs as types of mechanisms rather than distinct markets. Therefore, we will in the following often refer to an LFM that includes LEM mechanisms. However, it may not be desirable to implement a full suite of LEM and LFM mechanisms in all locations. Policymakers should be able to pick out the elements that make the most sense in their particular market design model from this report.

2.2.1. Local Energy Markets (LEM)

As briefly described in the introduction, we use the term Local Energy Market (LEM) in this report for a local market in which the retail energy prices paid by consumers, and perhaps also the prices received by producers, may differ from those "outside". However, it does not mean that a local market is a standard price zone or node in the electric power system. For example, Germany or NO3 (Central Norway) are not LEMs in our context. Since the wholesale price is the same in the LEM as outside, the special LEM retail prices will have to be incorporated in some other way. Alternatives include tariff discounts or premiums introduced by the DNO/DSO or by a third party like what +CityxChange (2019) refers to as "a local market operator" (p.7)[13] (LMO). Aside from pilot tests and demonstrations, such discounts or premiums may be considered if they are expected to reflect system-wide economic benefits or costs, and may vary with temporal and spatial conditions. If the adjustments leading to "special" prices in a given area are implemented as adjusted grid tariffs or taxes, the feasibility will also depend on political principles in the given country.

Besides pure price incentives, some may also have a special preference for local, renewable energy. The infrastructure of a local market could potentially facilitate this by allowing customers to track how much local energy they use in a way that is considered more credible than simply buying Guarantees of Origin (GOs). This can be a source of flexibility in itself, as energy users may shift their consumption to times when local generation is available.

Likely variants of LEM imply that local consumption adapts to the availability of local production, whether the stimulus comes from modified prices or the wish to use more local energy. This can be considered a form of local trading between the market participants.

[13] See footnote 2.

2.2.2. Local Flexibility Markets (LFM)

If a LEM introduces special energy prices for all energy consumption within it, it incentivises what USEF (2018) calls "implicit demand response" (p.4). Flexibility trading, on the other hand, is what USEF (2018) calls "explicit demand response" (p.4). Flexibility trading means that an owner of a flexible asset is paid directly by another party for the service of consuming or producing less or more or at a different time, or by a different energy carrier, than what they would without the payment. In a general sense, a flexibility market is a system or marketplace where this product is traded. In this report, a local flexibility market (LFM) means that the flexible LFM resources are situated in a particular location, and therefore can be drawn on in a coordinated way to address particular, local objectives. Normally, this will mostly mean the needs of a DNO/DSO to keep the net position of a section of the grid within certain limits (Section 2.1.1.1.), and thereby prevent congestion in the short or long term. This incentive may also carry over to those who want to connect assets to the grid. The ability of actors with local needs to access the LFM means that an LFM is also distinct from simply a collection of flexible resources in a certain location.

Most likely, trade in the LFM will benefit from being coordinated through a form of market platform where buyers and sellers can match their bids and requests. While this report is written from the perspective of a local platform serving local needs, it is important to note that many of the general principles may also apply to larger, more comprehensive platforms for flexibility services to e.g. DSOs, such as those described by USEF (2018). From a societal perspective it may not be optimal to have many small platforms, although they can be useful for testing and verification purposes. Figure 2.2 illustrates the main principle of an LFM platform as envisaged in this report. However, other variants are also possible.

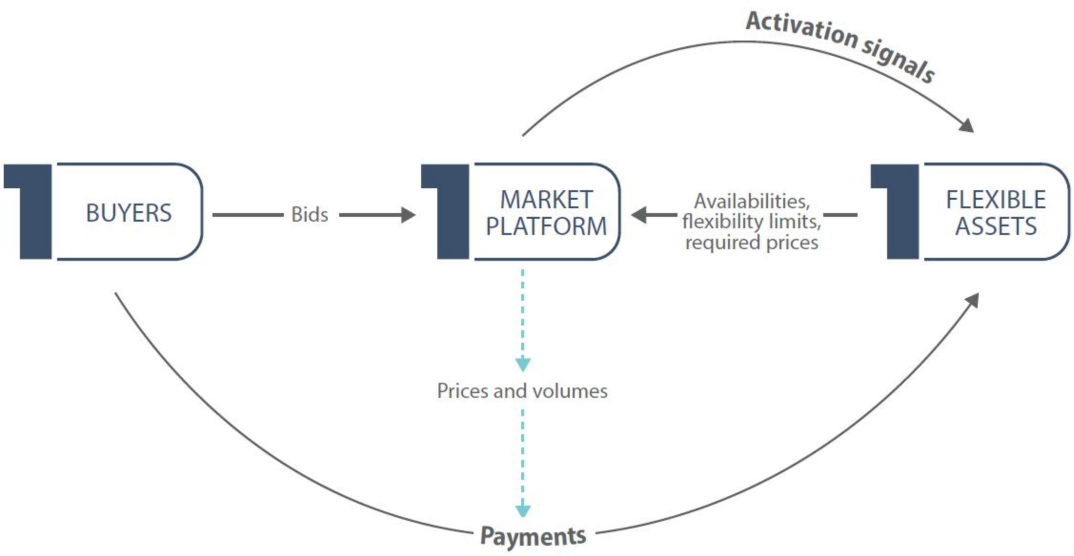

Figure 2.2. High-level overview of an LFM.

Flexibility payments can take several forms. A commonly used dichotomy is between reservation- and activation pricing (see e.g. Harbo, Hansen, & Heussen (2013)). Reservation pricing means that providers are paid for keeping an asset available at an agreed time, within specified limits, while activation pricing means that the provider is paid when the asset is activated and in proportion to the energy volume used. Reservation pricing allows for the possibility of trading flexibility that is never actually used, and can be formulated as long-term contracts. In contrast, the price of activation may be determined close to the activation time, and depend on the particular conditions at that time. While potentially better, activation pricing is more complicated to implement than reservation pricing. Furthermore, it can be a source of undesired incentives, especially of the sort that prosumers or automated systems could find it advantageous to shift the net position in the "wrong" direction (in order to get paid for activation to bring it back). These issues are dealt with in more detail in Chapter 4.

3 Components in a local market: assets, energy services, and sector coupling

To consider the potential value of a local flexibility market with energy trading, it seems necessary to map the applicable assets and energy services. That is, since the local market is made possible through the use of these resources. Furthermore, it will give a starting point for the opportunities at each location, considering that the locally available resources will vary in a local marketplace.

As essential components to the local market, the potential assets and energy services are carefully described in this section. We consider the characteristics of each category of assets and energy services, focusing on their flexibility potential, as well as their activation signals, which are relevant for the marketplace. Also, the concept of sector coupling is discussed in a similar manner. We focus on two kinds of flexibility when describing these assets: the ability to move production and/or consumption in time, and shifting between energy resources – sector coupling.

In the descriptions of assets and energy services below, the process of using a flexibility asset is illustrated with stock-and-flow diagrams,[14] where a box represents a state with in- and outflows as thick arrows. Green dots denote decisions that are inputs to the LFM, usually in the form of automated activation signals (see Figure 2.2), while blue dots represent other human decisions. The diagrams in Figures 3.1-3.5 are drawn with Powersim Studio (Powersim, 2017).

3.1. Assets and energy services

3.1.1. Standalone storage

This refers to storage technologies that are primarily intended for flexibility and for which the control signals are likely to be based primarily on economic signals such as prices and tariffs. One example could be batteries that are placed within the LFM, but which are not embedded in vehicles or other equipment. Figure 3.1. is a general illustration.

[14] See e.g. Sterman (2000).

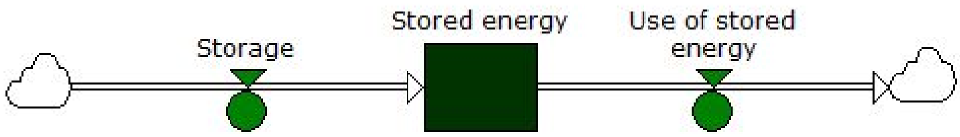

Figure 3.1. Stock-and-flow diagram for general standalone storage. It is governed by two primary control signals: energy input and energy output.

3.1.2. Embedded batteries, including electric vehicles

Embedded batteries, as opposed to standalone batteries, are understood to mean batteries embedded in devices and equipment, and therefore include everything from mobile phones to electric vehicles (EV). Like standalone batteries, this category is characterized by the possibility of providing flexibility by timing the volume of electrical charging and discharging. Nevertheless, there are significant differences between embedded and standalone batteries. First, changing the charging profile will come at a potential utility (comfort) loss to the user. Second, the equipment in which the batteries are placed can be moved outside of the LFM area, and therefore be charged outside. Third, it is often not possible to use the energy in the battery for anything else than running the equipment in which it is placed. However, for the particular case of EV charging, energy can be drawn from the battery to the grid (vehicle to grid or V2G), given that the technical requirements are in place. This can also occur both within the LFM area or outside it.

Among equipment-embedded batteries, EVs seem the most probable candidates for use in an LFM due to their volume, power, and flexibility potential. Therefore, only the EV example is described here, but we emphasize that the general characteristics are often transferable to other equipment-embedded batteries.

Building on Figure 3.1, an EV battery can be visualised as in Figure 3.2. Here, the two main decisions within the LFM are the local charging and the local V2G discharging . The states of the batteries are however also influenced by other decisions: charging and discharging outside the LFM, and by driving.

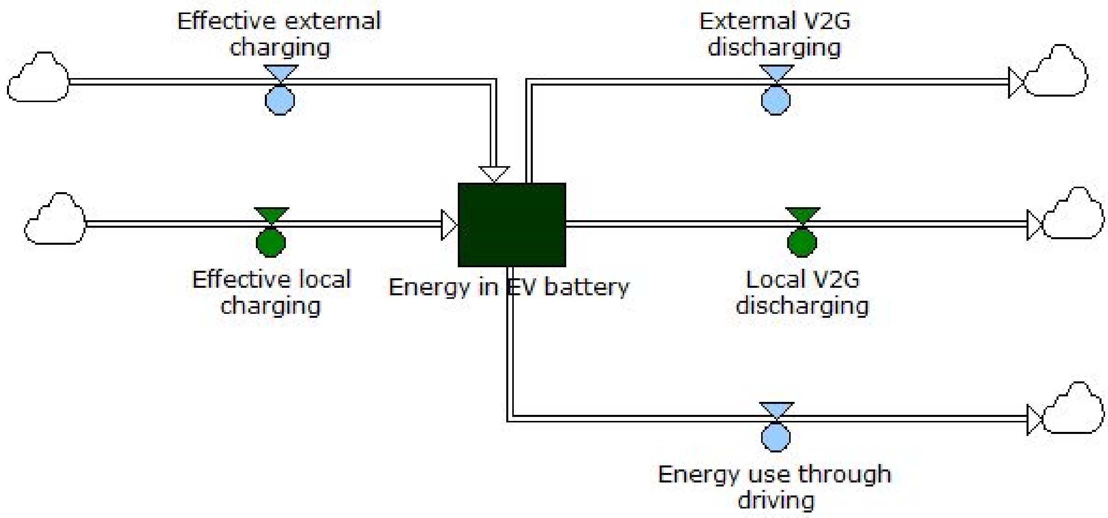

Figure 3.2. Stock-and-flow diagram for an embedded battery (EV battery example). The local market control signals are the local energy input and local V2G.

3.1.3. Tap water heating

Figure 3.3 illustrates the basics of a hot water tank for tap water.

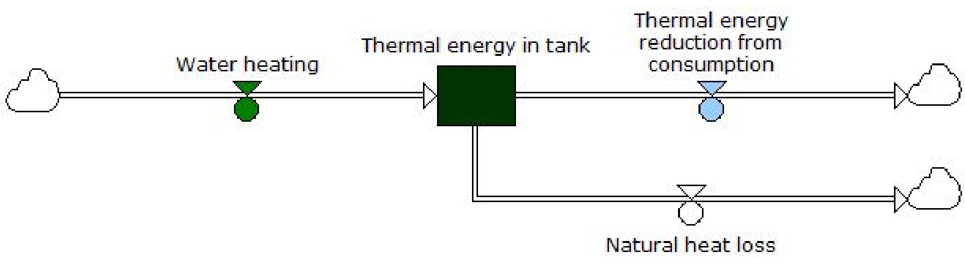

Figure 3.3. Stock-and-flow diagram for a water tank storage. The LFM control signal is linked to the amount of active water heating, while another (usually non-automated) decision is water consumption. Additionally, there is a natural rate of heat loss .

A water tank can offer flexibility both due to storage capacity and its, mostly, predictable consumption patterns. For example, it can be heated earlier than “planned” in cases of excessive power production. Due to water’s qualities as a heat storage, it can absorb energy at peak production hours and decrease its need of heat during energy intensive periods. Heating water tanks during peak consumption hours could therefore be avoided, through anticipating consumer patterns and energy production peaks. For instance, it is often unnecessary to supply private households with heated water during working hours. The timespan from heating to consumption could encompass several days, determined by the quality and size of the tank, and consumption pattern, thereby providing flexibility.

3.1.4. Space heating and cooling

Space heating and cooling refers to any process that may alter the temperature in (parts of) a building. The flexibility potential is restricted by the building's heat capacity and air quality constraints. These factors are implicitly set by building standards as they include limits on CO_2 content as well as building envelope constraints. The latter will impact the heat capacity of the building. Indeed, the heat storage capacity of the thermal mass in the building may play a significant role in providing flexibility in space heating.

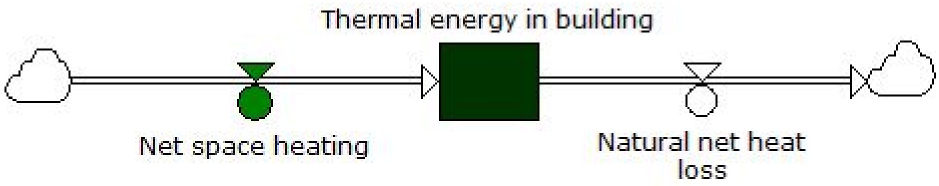

Figure 3.4. Stock-and-flow diagram of a space heating and cooling system. The key control signal is the amount of net space heating (i.e. heating or cooling), while the net heat loss (heat loss or gain) depends on outdoor temperature, building insulation, etc.

In theory, it may be possible to increase the difference in temperature between the active and inactive time intervals in a building. Meaning that the building user defines a minimum and maximum temperature for the time slots with human presence in the building (which will probably give a rather limited temperature span for each building), while the temperature outside of that time interval can be adjusted freely given another set of minimum and maximum temperatures.

3.1.5. Energy production assets

A local market can in theory include all kinds of production assets. However, in line with the context of the +CityxChange project, we limit the descriptions here to the primary energy sources that typically are available in urban areas. The technologies converting these sources are themselves usually considered mostly inflexible. Examples of such assets may be solar PV installations, small wind turbines and tidal turbines, which depend on solar irradiation, wind speed and tidal cycles, respectively. There is, however, one significant difference between the two first and the latter of the energy resources since solar and wind power output is subject to inherent intermittency while tidal power generation is highly predictable (Bhatia, 2014).

3.1.6. Appliances

In this context, the term "appliance" includes different assets like electrical devices and instruments that are commonly found in households and commercial buildings. Note that heating and water heaters are typically considered to be appliances, but are treated separately in this report.

An inflexible appliance, like a TV or a coffee maker, is either in use or idle, with little or no practical option of scheduling. A flexible appliance, such as a washing machine or dishwasher, however, may be scheduled to run and consume electricity at an arbitrary time – given that it performs its intended function according to certain rules or restrictions – making it a flexible asset. See e.g. Degefa, Sæle, Petersen, & Ahcin (2018) on the potential of such appliances.

3.2. Sector coupling

Sector coupling of energy systems is to look at how the different systems can play together in order to utilise the flexibility in each system.

3.2.1. Energy supply sectors and energy carriers

In urban areas, the energy supply sectors can include distribution systems for electricity, district heating and gas. These are all also considered to be energy carriers, which may be converted into energy services. Furthermore, they are interconnected with the assets and energy services detailed in the previous section. Therefore, electricity, district heating and gas is first described generally as well as with their relevance to assets and services in a local market.

Electricity

Electricity is highly versatile and it can, hence, be used for many purposes. It is used in almost all modern buildings. With assets and energy services in a local market as considered in Section 3.1., electricity is of significance for all. That is, decarbonisation may increase the share of energy services that use electricity, given that low carbon energy sources produce electricity. The locally available resources solar, wind and tidal all mainly produce electricity, apart from the example of solar heating.

District heating

A district heating system is limited to a defined geographical area. Thus must the production at any time correspond to the demand from customers. The system cannot export surplus energy or import energy from outside the defined area. Compared to the electrical grid system, district heating is a local energy system. District heating as an energy system is suitable for densified populated areas (cities).

Customers of district heating and cooling are typically residential or commercial buildings that have an internal hydronic system, i.e. water based heating system. The supplied thermal energy is used primarily for production of hot tap water and space heating. In addition, thermal energy can be utilised in appliances such as washing and dish washing machines and for local production of cooling. Consequently, district heating can be the energy carrier for both water and space heating, as well as the energy supplier for appliances.

Gas

Gas is widely used, and can be one of the energy suppliers for water and space heating systems in the context of a local market. Unlike electricity and district heating, the transportation of gas is not fully dependent on fixed infrastructure like grids and pipelines; it can also be transported by other means. Being a fuel, it is also a natural form of flexible storage. However, fossil gas obviously emits CO_2. Alternative technologies, e.g. power-to-gas, are required to use gas as a low-carbon source of flexibility.

3.2.2. Sector coupling in practice

In our context, sector coupling of energy supply means shifting between accessible energy carriers. It is one of the two types of flexibility we consider for an LFM, the other being the shifting of volume, or time of consumption, for a given amount of energy of the same energy carrier. In the following, we therefore consider the opportunities for sector coupling with respect to the energy carriers described in the previous subsection. Furthermore, an example of sector coupling in an interconnected water and space heating system is discussed.

Thermal energy from district heating can be utilised to reduce the load on the power grid, and thereby release electrical capacity for alternative use. The other way around, power to heat is an option, due to the flexibility of production in a thermal energy system. Also, gas can be used to reduce the load on the power grid through for example gas-to-heat. Furthermore, power-to-gas is possible. For some assets and energy services it is possible to switch between all three of the supply sectors.

Figure 3.5 illustrates sector coupling through the integration of water heating and space heating.

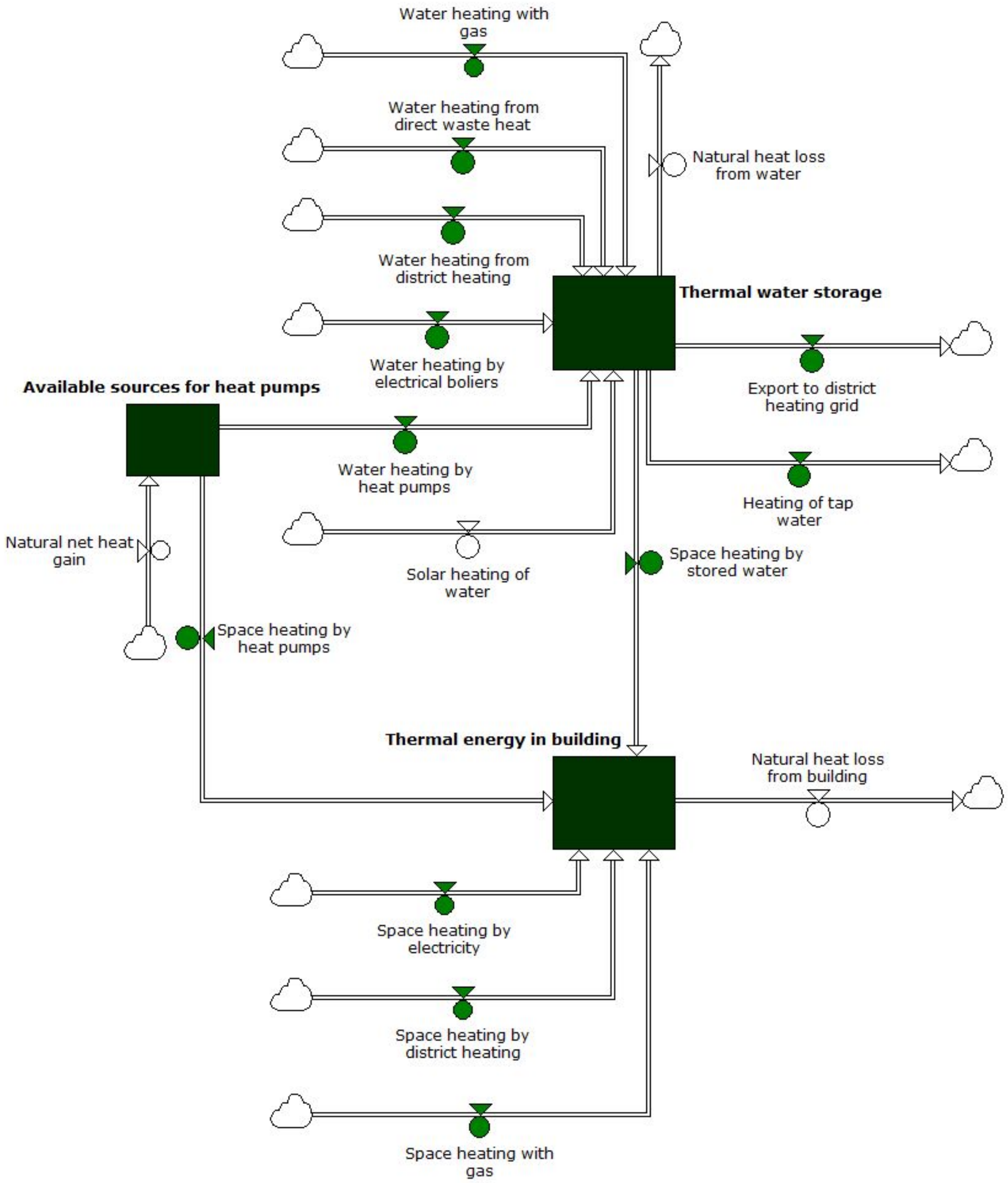

Figure 3.5. Stock-and-flow diagram for sector coupling with thermal water storage and space heating. This diagram is a comprehensive view of possible options; actual systems will typically only have some of these available. Several other couplings not shown here are also possible; for example, electrical batteries are not included. Note also that the diagram only explicitly deals with heating. However, cooling is in many cases also covered within this diagram framework, by simply interpreting it as negative heating.

In an LFM, a key value of sector coupling lies in how energy services can be achieved by different energy inputs. In this way, the system can avoid using energy sources that are temporarily expensive or unavailable because of grid constraints. Moreover, it can exploit the thermal storages that may already exist in water and space heating, which limits the need for potentially expensive electrical batteries. Locations with high potentials for sector coupling are therefore potentially good locations for LFMs. Yet, it should be considered that a high degree of sector coupling is not always compatible with other energy-related goals. For example, decarbonisation may require that the energy source for several energy services is required to be electric. The +CityxChange objective of PEBs may also limit reliance on sector coupling, since a PEB needs to rely heavily on the energy produced within it.

4 Design framework for a local flexibility market

This chapter answers the +CityxChange project's call for a "flexibility market design tool" (+CityxChange, 2018a, p.25). The design tool is a set of principles and a standardised method for how to proceed when considering LFMs in European countries. Using this framework, the direction for the market design should follow logically from data about local objectives and conditions.

Some principles are expected to apply to most LFM designs. First, several important principles of existing, best-practice wholesale power markets will normally be retained, or, to the extent possible, introduced if they are lacking. Second, in accordance with the objectives of +CityxChange, the LFM should allow market access to all - even the smallest – assets in the LFM area, and should to the extent possible promote +CityxChange PEB development and operation.

The chapter is structured as follows. Section 4.1. describes some of the common principles behind energy market design in general, and how these may be adhered to in LFM design. Section 4.2. discusses how to "reach" locally owned flexible assets, allowing them market access. Section 4.3. describes alternatives for the LFM's market operation system, defined here as a set of price-setting mechanisms. Section 4.4. describes alternatives for the distribution of roles between institutions. Finally, Section 4.5. systematises the described market design options and maps them to local conditions and objectives. Recommendations are summarised in a relationship map.

4.1. Principles of energy markets to be considered in LFMs

Within the scope of developing +CityxChange LFMs, the aim is not to describe "optimal" market designs directly, neither at the large nor at the local scale. The LFM solutions are incremental improvements, not fully developed components of an envisaged ideal energy system. Moreover, the LFMs are viewed through the lens of a particular objective in the +CityxChange project: positive energy blocks (PEBs). However, it is considered that PEBs and PEDs will be implemented within jurisdictions where PEBs are not necessarily prioritised objectives. Moreover, commercial actors normally have no particular interest in PEBs in themselves unless the incentives intended to generate them entail profit opportunities. We assume that a prerequisite for dispensations from existing regulations is that the demonstration projects and the associated market designs do not compromise the objectives of the jurisdiction within which they are implemented – at least not to an extent where misalignment with these are not outweighed by the benefits of the projects.

Hence, although benefits of local flexibility are promising, fundamental principles of wholesale electricity markets must still be respected (THEMA, 2016; THEMA & Multiconsult, 2018). Such principles may differ somewhat between countries, and in some countries a given principle may currently only be long-term goal. Table 4.1 below lists typically recommended market design principles and a brief note about what they, if adhered to, are likely to imply for LFM design in the +CityxChange project.

Key principles of energy markets	**Explanation**	**Likely implications for LFM design**
Fair cost allocation for public goods	The payment for public goods like grids and similar infrastructure (for electricity, gas, and district heating) should be allocated in line with overall political objectives for distribution	LFMs should normally not exempt participants from paying their share of the costs of the grid infrastructure they rely on. If exemptions from grid payments are granted, they should reflect real savings of grid costs or other distributional objectives.
Free choice of electricity suppliers by customers	Electricity customers must be able to freely choose and change electricity suppliers.	Participation in an LFM should either 1) not require participants to change their electric power supplier, or 2) ensure that if participation requires a particular "LFM supplier", participants should be able to change to or from it as easily as between others.
Market access	All energy resources that can provide value should have non-discriminatory market access.	The LFM should to the practical extent possible allow participation for all flexible assets, even very small ones.
Monopoly regulation / development of grid infrastructure	The development and operation of the grid (energy transport) is a regulated natural monopoly not open to competition.	LFMs should be possible to implement without altering the grid infrastructure or who owns it. However, if the current revenue models of grid operators discourage using local flexibility as an alternative to grid investments in an economically efficient way, they may need reconsideration at a national level.
Security of supply	Ability to provide end users with an uninterrupted supply of energy.	LFMs can strengthen security of supply through more local generation and flexibility. This value to the system should be rewarded. However, the LFM incentives should not displace grid upgrades to the extent that security of supply is unacceptably endangered. Finally, an LFM aiming to provide system services to a DSO needs to be highly reliable, and should therefore not be too small.

Quality of electricity supply	Voltage and frequency can be guaranteed reliable.	In line with ongoing EU objectives, the DSO role should be developed (European Commission, 2016). Local Market Operators (LMOs) or Community System Operators (CSO) can also provide services that avoid potential problems for a DNO/DSO.
Market liquidity	There are enough actors to prevent strategic market behaviour.	Ensure that the LFM is not too small, and/or uses price-setting rules that mitigate strategic behaviour.
Asset utilization	Multi-purpose resources are fully utilized (e.g. an asset consuming energy can provide flexibility).	The LFM should ideally not monopolise local assets and prohibit them from adapting flexibly to the outside "external" markets. However, priorities between DSOs, TSOs and BRPs must be set.
Practical feasibility	The market design must be possible to implement, understand and operate by all market players.	A high degree of automation is likely to be necessary, especially in LFMs with frequent trading. Intermediaries between the asset owners and a local market platform (e.g. retailers) can ensure hassle-free access for consumers and at the same time provide detailed price bids to the platform. However, the market platform should also allow direct access if standard requirements are met.
Data privacy	Data privacy should be aligned with national regulations.	Consult output from +CityxChange Tasks 1.1. and 11.6.
Cybersecurity	Cybersecurity should be aligned with national regulations.	Consult output from +CityxChange Tasks 1.1. and 11.6.

Table 4.1. Typical principles of energy markets and their likely implications for LFM design.

4.2. Overcoming barriers to access local flexibility assets

One of the goals of the +CityxChange project is to allow flexible, small-scale assets to contribute to the energy system. However, accessing these resources, which may include privately owned EVs, heating systems, washing machines, etc. can be challenging. In this subchapter we discuss methods to approach this problem in LFM design.

For the owner of a flexible asset, shifting energy use to a different time or a different energy carrier often implies a cost. This cost can mean reduced comfort, or a monetary loss if the asset already has an optimised schedule based on e.g. hourly spot prices. An LFM needs to identify these costs and allow buyers of flexibility to bid against them. In doing so, an LFM can address two main shortcomings in current markets:

1. **Missing incentives (economic barriers):** Given that flexibility has a cost, an asset owner normally requires a monetary reward to be flexible. However, this signal is often weak or lacking for end-users in current energy retail prices. Hence, even cheap flexibility may be left idle.
2. **Complexity and time use (social and technical barriers).** For individual, small-scale consumers, being flexible may be more trouble than it is worth. Even with better price incentives, they are unlikely to manually optimise their washing machines and heaters in the same way professional utilities optimise their power plants. Automation, simplicity, and user-friendliness are currently not at the required levels.

In the following, we deal with how these challenges can be addressed in a local market.

4.2.1. Introducing local incentives for flexibility

For LFMs to work, monetary incentives that address the key objectives described in Chapter 2 are necessary. As described there, most of these objectives imply compressing the net position of the LFM and keep it within certain limits (see Figure 2.1).

Such incentives already exist to various extents, as they include e.g. hourly spot prices, which may be correlated with high loads locally (e.g. cold days), and grid tariffs based on individual consumers' peak loads. Where such incentives are currently lacking, implementing them could in itself alleviate local grid problems. However, they do not always accurately target the challenges caused by the collective net position of a particular local area, meaning that other instruments also may be necessary. These can be implemented in an LFM, which can also achieve a fairer allocation of the rewards for flexibility.

4.2.1.1. Types of incentives

We have identified several different classes of incentives that could lead to an LFM:

1. **A DSO or an LMO as a buyer of local flexibility.** This means that a DSO pays owners of flexible assets for flexibility, or that a third-party entity like an LMO could potentially act as a buyer in a similar way as long as it is provided with a source of revenue (see the next section) and the DSO retains overall system responsibility.
2. **Connection requirements.** A requirement for connecting new consumption or production assets may be that they maintain their net position within agreed limits. In this case, the incentive comes from the aim of adhering to such an agreement, and any penalties that may apply if they do not.
3. **Particular grid tariffs or equivalent.** E.g. a DNO or an LMO could implement special energy price adjustments within the LFM area. Depending on their design, these could incentivise and enable trading of flexibility between local participants.

4. **Willingness to pay extra for locally produced energy.** The LFM could facilitate transactions where participants who are willing to pay local producers a premium are able to do so. This would be a form of local energy trading.

4.2.1.2. Sources of incentives

A natural next question then becomes: who should introduce special incentives in the LFM? In the most fundamental sense, the answer is "society" since local congestion, instability, grid losses, and grid investments are real economic costs. However, European countries differ with regards to who has the incentives and the mandates to reduce these costs. Hence, unless the LFM incentives are financed by a direct public subsidy or tax exemptions, it becomes necessary to identify the main stakeholders.

In many cases, a central stakeholder will be the local DNO/DSO (hereafter, DNO for generality). While a DNO's costs ultimately may be transferred to its customers, it is often the first-line payer of the costs local markets intend to reduce. Hence, to the extent an LFM reliably could reduce or delay e.g. grid investments, the DNO should in theory be willing to facilitate it.[15]

Another set of stakeholders may be the people located in the area under consideration. This could for example pertain to how some of them may want to use more locally produced, renewable energy. Local consumers and producers may also be subject to the costs of (avoiding) congestion and grid losses directly. For example, consumers may need to pay the DNO a fee, or agree to keep their net position within given limits, to be allowed to connect assets to the grid. They may also face time-of-use tariffs. However, these individual incentives are not necessarily enough to entail flexibility *trading*, and local residents may have limited possibilities to make the necessary changes without the DNO. Therefore, the DNO may be a gatekeeper also in this case. Yet, prosumers (or prospective prosumers) may in some cases be able to introduce their own system of incentives, e.g. through an LMO, to collectively comply with the overall requirements of a DNO.

4.2.2. Reducing complexity and time use for participants

A major challenge for eliciting local flexibility is that unlike current professional energy producers, LFM prosumers are normally not as interested in taking an active role in day-to-day market operations. Hence, automation is required. However, the boundaries within which automation takes place must still be governed by consumer preferences.

In the following, we present different options for overcoming this complexity barrier. These can be grouped in two broad categories: 1) the extent of intermediaries between the flexible asset and the ultimate buyer, and 2) pricing models for flexibility. We describe these in turn.

[15] If it is not, its revenue model may need revision. This would have to be addressed at the national level, the details of which are beyond the scope of this report.

4.2.2.1. Alternatives for market involvement from local actors

In an LFM, market involvement by its participants can range from almost none, for example only through a yearly flexibility auction, to frequent, daily operations. Otherwise, market operations are automated. The expected degree of involvement, which can be a guideline for LFM design, probably depends on the type of participants. Households and small businesses, for example, will probably not have the interest nor the knowledge to be involved in frequent energy and flexibility trading. These agents are likely to prefer highly automated systems or systems that are easily understood (there may be a trade-off between these two qualities). Owners of large commercial or industrial buildings may however have the ability and interest to be more engaged in the market. They may even have professional staff (e.g. building managers) that can, at least on a part-time basis, be involved in market participation as a part of their building optimisation tasks.

In almost all LFM designs, however, some degree of automation is required. Setting the rules for these automated systems, however, requires involvement by humans. While this kind of action may already be familiar to participants with smart homes, the additional, potentially complicating factor in an LFM is the negotiation with other human agents when these decisions are made. This is probably not required for each activation of flexibility, but applies at least whenever longer-term contracts are formulated and signed.

Figure 4.1 illustrates the diversity of possible pathways from assets to final buyers. Note that this diagram is not a suggested market structure, only a way to illustrate the many possibilities. Prosumers can offer the flexibility of their assets in several ways: through intermediaries like aggregators or energy service companies (ESCOs), directly to "local needs" (meaning typically the DNO/DSO or other market participants), directly to external markets (e.g. an aggregator serving BRPs and/or the TSO), or to these final (local and external) buyers via a local market platform. While much local trade will probably be handled within the platform, it may co-exist with several other forms of trade within the LFM area.

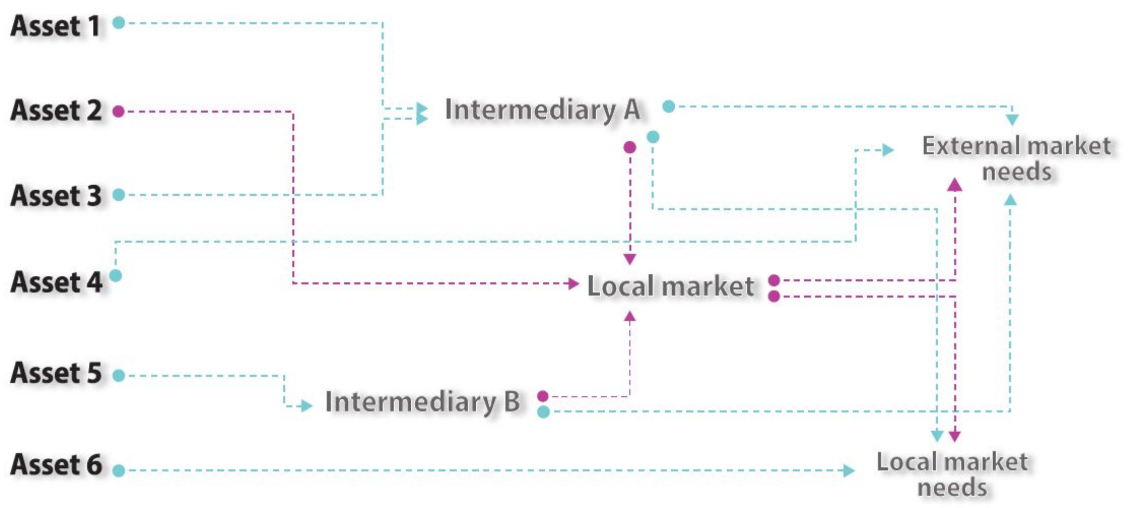

Figure 4.1. Example of different "pathways" for flexibility in a local market area. The lines represent decisions to offer flexibility directly to another party or into a market platform. The purple lines illustrate the trade that goes through the local market platform. These are the main focus in this report.

4.2.2.2. Pricing alternatives for flexibility

In the design of LFMs, key decision points lie in both the linkages shown in Figure 4.1 and in the price-setting mechanisms in the market platform. Detailed suggestions for price-setting mechanisms (market operation systems) are described in Section 4.3. However, it is useful to describe the broad classes of payments for flexibility already here. These options may also apply outside of the local platform, for example in how intermediaries procure flexibility from asset owners. Hence, the alternatives for the market platform can often be generalised and thereby accommodate even very complex networks of pathways with many intermediaries.

Flexibility contracts offered at various points in the pathways shown in Figure 4.1 can be placed in several broad categories. Three main classes, which can be implemented in local markets in various combinations, are dealt with here:

1. **Unpriced contracts.** Here, a consumer simply sets certain limits for a flexible asset and offers it as available to the local marketplace or an intermediary with the hope of minimising his or her energy bill, but with no upfront or agreed payment. Hence, flexibility providers do not know how much they will earn when they offer their assets to the market. It is only over time that they may learn from experience approximately how much their flexibility is worth, and heuristically adjust how they set the limits for their assets. This contract is similar to a retailer offering 'smart control' of certain consumer assets with a spot-price contract, i.e. the consumption is adjusted to the cheapest spot-prices with no guarantee of the total savings.
2. **Reservation pricing.** This means that flexibility providers set limits for their flexibility assets based on prices agreed with an intermediary, system operator, or LMO. Providers are not paid according to the activation of their assets, only to have

them available at certain times.The simplest version of this could be that the provider is offered a fixed yearly reduction in his or her energy bill in return for a degree of control of an asset. Reservation prices could be set in auctions, as suggested by e.g. THEMA (2016) and implemented in the BQDM program (ConEdison, 2016).

3. **Activation pricing.** Here, flexibility providers, intermediaries or automated systems set detailed prices for how their assets can be regulated at different times. In several cases, this can be expressed as a price per kWh of reduction or increase in their net position at a given time. Activation pricing is more complicated for market participants than unpriced contracts and reservation pricing. As described in more detail in Section 4.3., it could also create unintended incentives for exploitation unless countermeasures are used. However, it has a theoretical potential for higher economic efficiency. A particular version of activation pricing is through production or consumption “quotas”, as explained in Section 4.3.2.

4.2.2.3. Combinations of intermediaries and pricing models

The choice of pricing options combined with the many possible pathways in Figure 4.1 suggests a wide range of potential solutions. However, some appear more plausible than others. A possible first option is that prosumers sell reservation-priced or unpriced flexibility to intermediaries (including ESCOs and retailers), who in turn use their portfolios to bid activation-priced flexibility into the local market platform. An advantage of this approach is its relative simplicity from the prosumer’s perspective. Competing intermediary ESCOs or retailers can for example simply offer the prosumer discounts to their energy bills in return for some access to their flexible assets, which essentially would be a form of reservation pricing. This can even be implemented for prosumers with fixed price contracts (e.g. a fixed price per kWh of electricity).

A second option is that prosumers enter activation prices directly to the platform, possibly through an automated system. This may require that prosumers already pay time-dependent variable rates and/or tariffs. In this case, prosumers have an incentive to time their consumption- and production patterns individually, also in the absence of an LFM. Prosumers can for example set flexibility limits for their assets and use an automated system to optimise them over a time span (like a day). Activation prices could then be calculated as the costs of deviating from that first optimisation, while also taking the same, pre-set flexibility limits into account. Decisions on flexibility limits may range from long-term, stable comfort limits, like space heating, to more intermittent, idiosyncratic decisions like electric car charging.

Figure 4.2 illustrates the two broad options.

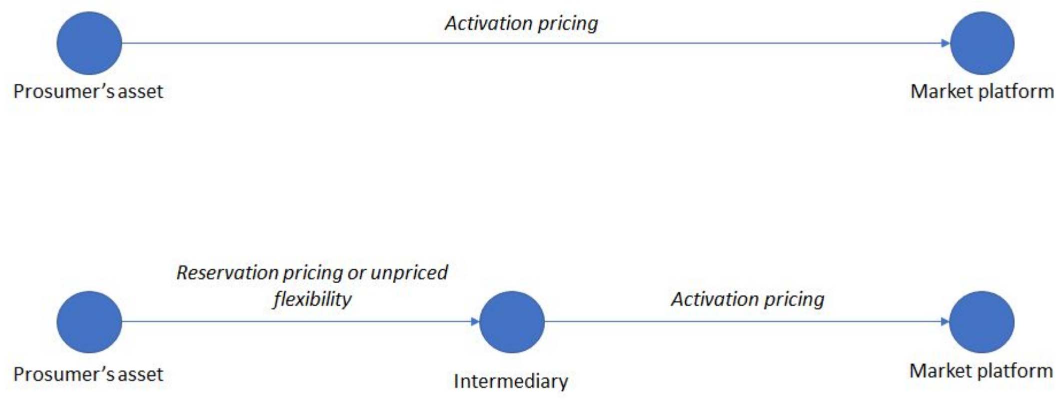

Figure 4.2. Two options for how activation prices can enter the local market platform: directly from an asset or through an intermediary.

4.3. Options for a market operation system

In this part we present a high-level overview of options for LFM price-setting mechanisms (elements of a market operation system) to be tested in +CityxChange. We consider several alternatives, which may be considered separately or as components of a single system. All are focused on the real economic and social objectives of LFMs, described in Chapter 2.

The options considered are:

1. Local energy market (LEM) mechanisms, for the purpose of:
    a. Absorbing excess production
    b. Reducing peak demand
2. Flexibility trading between LFM participants, for the purpose of:
    a. Absorbing excess production
    b. Reducing peak demand
3. The DSO or LMO as a buyer of flexibility:
    a. With only reservation pricing
    b. With both reservation and activation pricing

Of these alternatives, 1a, 2a, and 2b can be seen as examples of trading between the LFM participants. This means that LFM participants can be considered to trade energy (1a) or flexibility (2a, 2b) with each other. The third category (3a, 3b) describes flexibility trading between the LFM participants and an institution like a DSO or LMO. Option 1b is neither, it is simply a price signal imposed on the local market. In terminology of USEF (2018) the mechanisms in 1a, 1b, 2a, and 2b would mainly be intended as a means of grid capacity management, while those in 3a and 3b could also be used for congestion management (see Section 2.1.1.1.).

The three main categories here are currently expected to often be suitable for the three different time resolutions outlined in +CityxChange (2019, p.20): >=1 hour (P1), 15-60 minutes (P2), and <15 minutes (P3).

4.3.1. Local energy market mechanisms for flexibility

LEM mechanisms, as defined in this report, means potentially different retail energy prices in the LFM than "outside", but without the local market being a fully developed and integrated price zone or node. Hence, the difference in retail prices between the LFM and the "outside" price has to be implemented by other means than the wholesale price. Unless an LFM with such mechanisms is fully financed by the LFM participants themselves, the feasibility of such price adjustments may depend on political principles in the relevant country. For example, some countries may not allow different grid tariffs within the same DNO area. This issue is left aside for the moment, but returned to in Section 4.5. In this section, however, we simply describe how LEM mechanisms can be formulated in the case that they are considered worthwhile and politically acceptable, or in pilot/test cases.

LEM mechanisms are price signals, and not by themselves intended to be relied on to prevent congestion when it is about to occur. However, like grid tariffs, they could help with systematically evening out the LFM's net position. This can reduce the frequency of potentially congested situations, and stimulate investment in flexible assets that could prevent congestion in the long term. They can also complement local flexibility trading with activation pricing by mitigating incentives for harmful exploitation by LFM participants or automated systems. This issue is returned to in more detail in Sections 4.3.2., 4.3.4., and 4.3.5.

We consider two main market mechanisms, depending on the net position of the LFM (total production minus consumption) is considered too high or too low. Both mechanisms may however be implemented in the same market.

4.3.1.1. LEM mechanisms to absorb excess surplus energy

If the objective is to reduce the LFM's production surplus, a natural approach is that the energy price during times of surplus should be lowered in order to incentivise increased consumption and storage at that moment.[16] The following example illustrates how this may be implemented. Consider a simple LFM with three participants with solar panels: A, B, and C. Assume that in a given hour, their individual net positions for electricity are as follows:

A: +5 kWh/h (net producer)

B: +3 kWh/h (net producer)

C: -6 kWh/h (net consumer)

[16]This can mean a reduction compared with today's price when the LFM has surplus production, raising the price when it does not have a surplus, or a combination of both. The important principle is that there is a difference.

In this context, only C is considered to be a net consumer. Both A and B produce more than they consume, and together provide 8 kWh/h. This can be considered the gross surplus or local (net) supply of the LFM. In the following, we apply the premise that actor C is then considered to buy 6 kWh/h of locally produced electricity, while the remaining 2 kWh/h is sold "outside" the LFM. This can be considered the LFM's net surplus in that given hour.

Next, assume that the LFM is able to finance a discount for each kWh of the LFM's net demand (the sum of all the negative net positions in the LFM) that is covered by the gross surplus. While net consumers (in this example, C) may receive this discount, the producers A and B could receive their standard price for surplus energy.[17] If so, this mechanism does not in itself reward local producers through a higher price. However, assuming that local consumers and owners of storage are flexible, the price discount can cause more of the local production to be absorbed locally.

The effect of this mechanism is fairly straightforward whenever the LFM has a net surplus. If so, every net consumer pays the discounted price. Figure 4.3 illustrates this example. The supply curve of the market is the green line, which represents how much net supply that is available locally at which price. This consists of the local gross surplus of the LFM and the energy volume needed from "outside" the LFM, for which the normal price is paid. Hence, the generation consumed by each prosumer himself/herself is not included in this curve. Likewise, the demand curve represents the demand after subtracting self-generation, i.e. the sum of all the negative net positions. In a market without the discount, the quantity demanded would be Q1. With the discount, and with flexible net consumption represented by the demand curve (orange), the quantity demanded is Q2 (the demand curve shown in this diagram may show more flexibility than what is realistic, but some exaggeration is useful to illustrate the point).

[17] This level differs between countries, and may include subsidies.

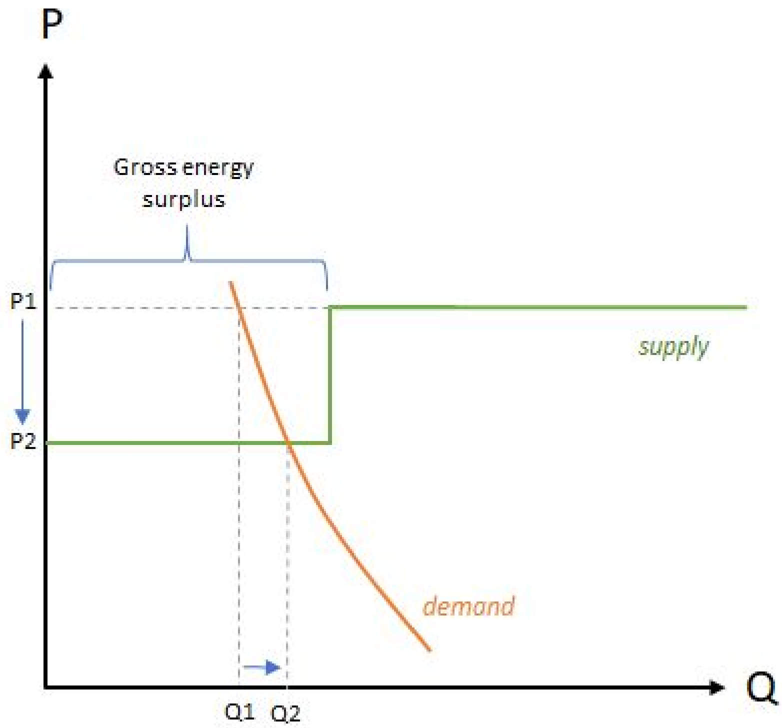

Figure 4.3. A market with a discount (P1-P2) increases the quantity demanded to Q2.

However, the LFM may not always have a net surplus. Figure 4.4 illustrates this case.

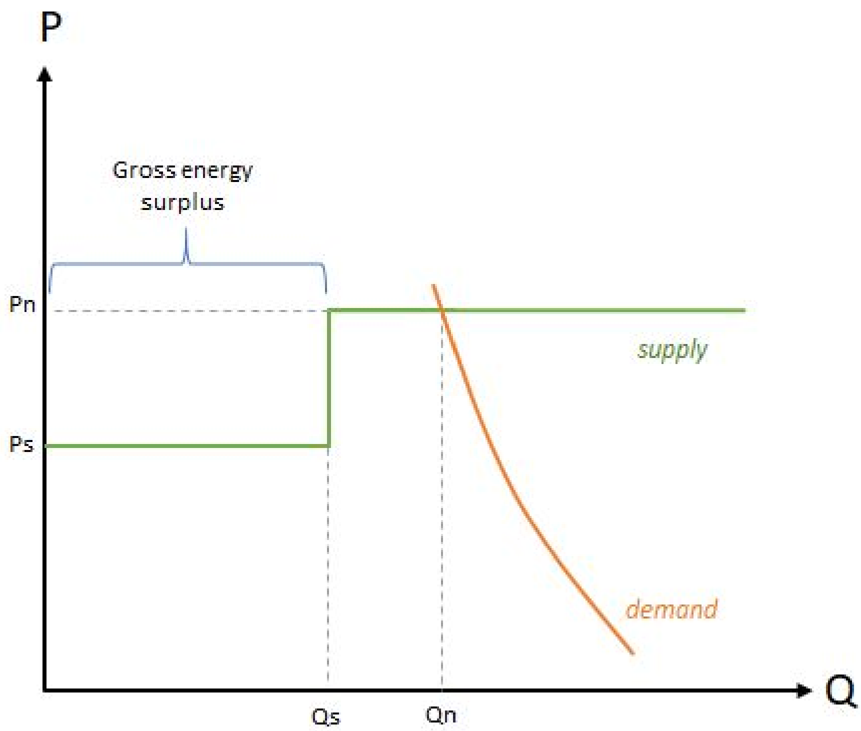

Figure 4.4. An example where the gross energy surplus does not cover all the net demand.

Here, the LFM design must decide whether consumers should pay 1) the regular price *Pn* for all their net consumption (*Qn*), or 2) the regular price *Pn* for the volume (*Qn* – *Qs*) but the discounted price *Ps* for the LFM's gross surplus *Qs*. Option 2 will require a mechanism for allocating the total discount among the LFM participants.

Option 2 would incentivise more consumption even when the LFM's net position is negative. If the main purpose of the market mechanism is to help with preventing outgoing congestion, this may not be a very useful incentive. In some circumstances it could save on grid losses, but this would depend on the overall scale of the LFM and its surroundings and would need to be carefully considered.[18]

Capturing special preferences for local energy

Simply monitoring the local gross surplus could enable even more local flexibility than price signals alone. Some LFM participants may wish to consume more local, renewable energy, and may be willing to shift their consumption to periods when a local gross surplus is available. Since this means a deviation from their otherwise optimised consumption pattern, they are effectively willing to pay somewhat more for local generation than the regular spot price.[19]

In a European context this also requires, however, a higher willingness to pay for local energy than for certificates from the existing Guarantees of Origin (GO) scheme. Buying GOs may be considered insufficient by consumers who want a reliable estimate of how much local, renewable electricity they physically use. Operationally, a willingness to pay more for local generation than for ordinary GOs can be thought of as an adjustment in the demand curve when the LFM has a large gross surplus. One simplifying heuristic could for example be that a different demand curve will apply when the LFM is in a net surplus, as illustrated in Figure 4.5.

[18] Tariffs for both consumption and production can reflect marginal losses (EC Group, 2015; Pérez-Arriaga et al., 2016). Incentives from an LFM can in some circumstances approximate this principle, and could therefore be considered when such tariffs are absent or incomplete.
[19] Unless their cost of this load shifting can be considered to be zero.

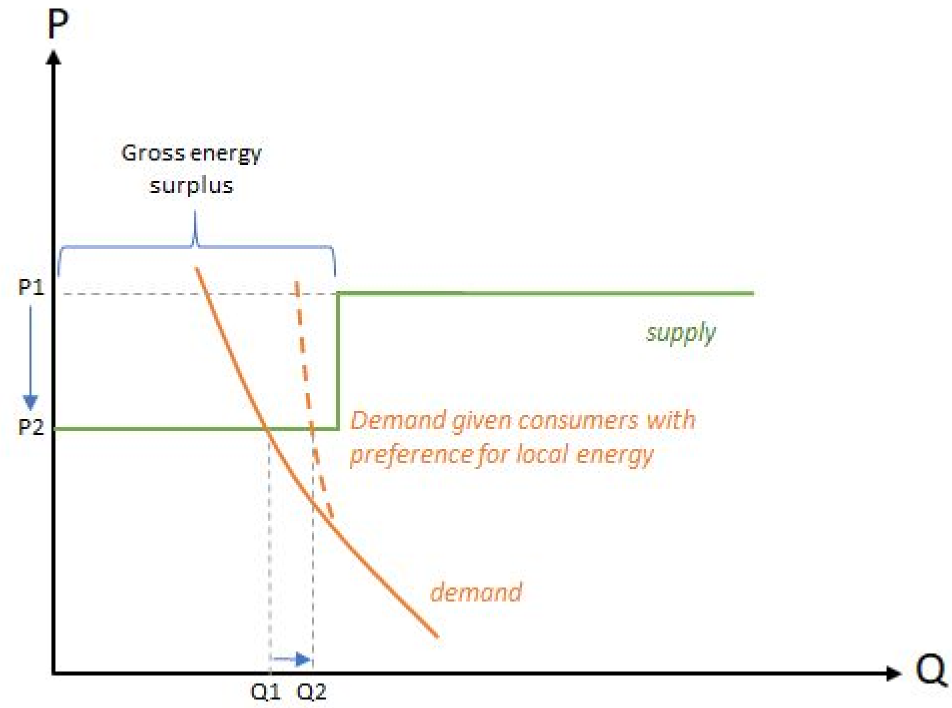

Figure 4.5. Effect of extra willingness to pay (lower price elasticity) when consumption can be covered by locally produced energy. This figure shows an example where a net surplus entails a different demand curve.

4.3.1.2. LEM mechanisms to mitigate excessive load

The principle applied in the previous section is adaptable to a reversed situation where there is a need to limit the LFM's net load. In this case, the market could impose a price premium on consumption whenever the LFM's total net load (negative net position) exceeds a given level (Backe, Kara, & Tomasgard, 2020).

The concept is illustrated in Figure 4.6, which also includes the price discount for gross surpluses from the last section. Here, a premium (P2-P1) is added to the regular price (P1) when the total net quantity demanded of the LFM exceeds a certain pre-set threshold (T). The total quantity demanded now becomes Q2 rather than Q1, which would be the result without the premium.

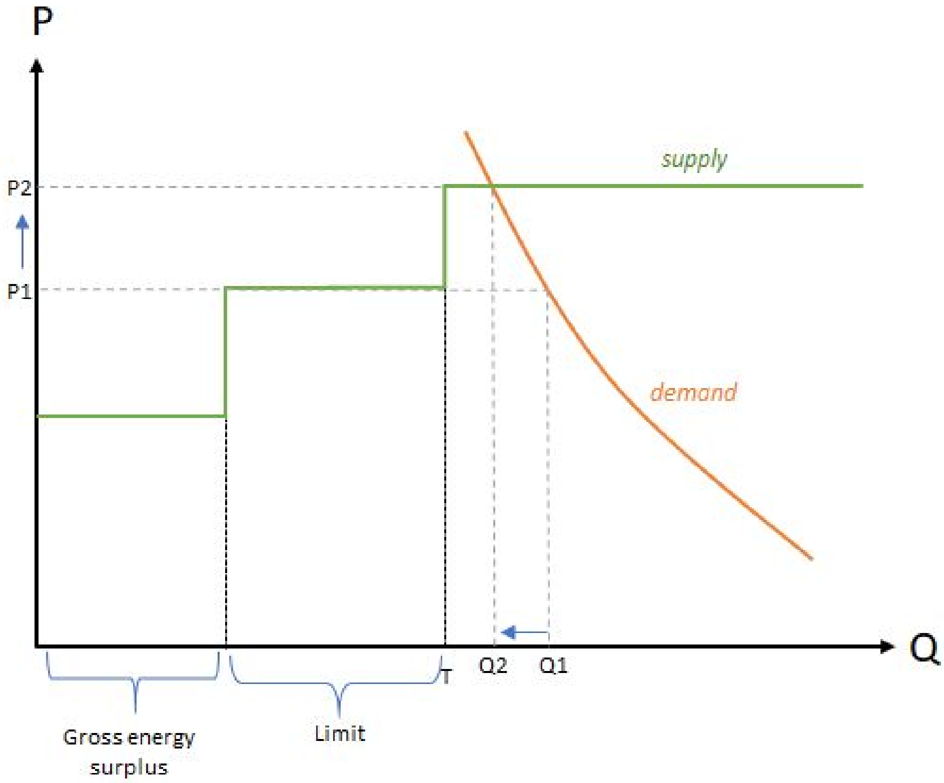

Figure 4.6. In this example, when the LFM's total net demand exceeds the gross energy surplus plus a limit, a price premium is added per kWh consumed. The higher price reduces the quantity demanded.

This approach is potentially effective, but requires that someone imposes such premiums. Potential LFM participants are unlikely to join such a scheme voluntarily, unless it comes as a requirement for participating in an LFM that provides them with other benefits. In voluntary markets and tests, it may also be possible to attract interest by retaining the current price but allow the LFM a discount whenever their total net load is below the limit. This will effectively make energy cheaper within the LFM than outside it, which may be popular among its participants but not conducive to PEBs with a yearly cumulative production surplus. In either case, however, the difference between the price for consumption above or below the threshold will encourage flexibility.

4.3.2. Flexibility trading between LFM participants

The schemes described in Section 4.3.1. imply individual adaptation to different prices, but not by themselves flexibility trading between LFM participants. However, they do introduce an underlying motivation for trade. This follows from the potentially high collective willingness to pay other participants to adjust their consumption or production, even by just a little, since this would lower the bill for everyone. Facilitating such trade can provide those who are flexible with an extra reward, causing more flexibility to be unlocked.

This general idea carries a risk, however. LFM participants could increase their nominally non-flexible consumption in order to make the LFM cross the threshold, and then be paid to have their flexible assets activated. Additionally, some variants could be hard to gain acceptance for. For example, the concept that one's own energy bill depends on a neighbour's actions may be considered unacceptably risky for some. To implement or test such flexibility trading between participants, it is necessary to address these issues carefully in the LFM design.

Sections 4.3.2.1. and 4.3.2.2. describe an approach to flexibility trading between participants. It can be thought of as a "quota" system, somewhat analogous to cap-and-trade markets for pollution. It is inspired by the principles of the Norwegian regulator NVE's proposed grid tariff scheme of "subscribed capacity" ("abonnert effekt" (NVE, 2017, p.viii)), and a forthcoming paper on how a group of consumers could share a common subscribed capacity (Backe et al., 2020). The introduction of flexibility trading between participants in such a system is a natural extension of it to address the goals in +CityxChange.

The scheme described in the following two sections is a form of flexibility activation pricing. Activation pricing is however subject to several challenges that may not be fully solved by the mechanisms described below. Especially, the potential for exploitation may not be possible to eliminate fully. Also, the subjection of the market rules to machine learning systems could uncover possibilities for exploitation that are not recognised at this point. Continued research, testing and re-assessment in +CityxChange Tasks 2.3, 2.5 and 5.10 will therefore be crucial to check the viability of these options.

4.3.2.1. Flexibility trading between LFM participants to absorb surplus energy

We first consider the case where a surplus of production is the problem. Here, we use an example where the LFM is not allowed to have any net surplus at all. As will be described later (Section 5.2), this may be a requirement of a Community Grid System. However, the same mechanisms would also apply if the upper limit for the LFM's net position were above zero.

The starting point for this mechanism would be that each LFM producer has a fixed, individual limit to their production surplus. With a collective limit of 0 kWh per time interval (as an example, we use the unit kWh/h here, but smaller intervals may be chosen) the individual limits would also be 0 kWh/h before accounting for the possibility of flexibility trading. Internal flexibility trading in the LFM would then allow producers to buy "production quotas" to temporarily raise their individual limits. To address the problem of grid constraints directly, each quota should belong to one period only (e.g. 1 kWh/h, in hour 5) and it should not be possible to save them for future periods.

As an example, consider a market with three participants (A, B, and C) where each individual limit is 0 kWh/h. Production quotas are then interpreted as net deficits, which means that net producers initially have no quotas while net consumers have some. In a given period, assume that the net output of A, B, and C would be as follows before flexibility trading is accounted for:

A: +3 kWh/h (net producer, needs three quotas)

B: -1 kWh/h (net consumer, one quota to spare)

C: -1 kWh/h (net consumer, one quota to spare)

In this case, assume that A would receive no payment for his/her surplus, since the limit is zero.[20] However, the LFM will allow him/her to purchase production quotas from B and C. Altogether, B and C have two "unused" production quotas (2 kWh/h) that are sold at no cost since their net positions are assumed to already be optimised. However, as two quotas is not enough, B and C will need to consider whether they are willing to increase their consumption in order to free up a last quota. This will not be costless, although the increase often means moving consumption from another period, not an increase in the total consumption per day. However, if B or C can provide this for a cost that is lower than A's loss of revenue, the quota will be supplied. Figure 4.7 illustrates this example, where it is assumed that B has the cheapest necessary last quota.

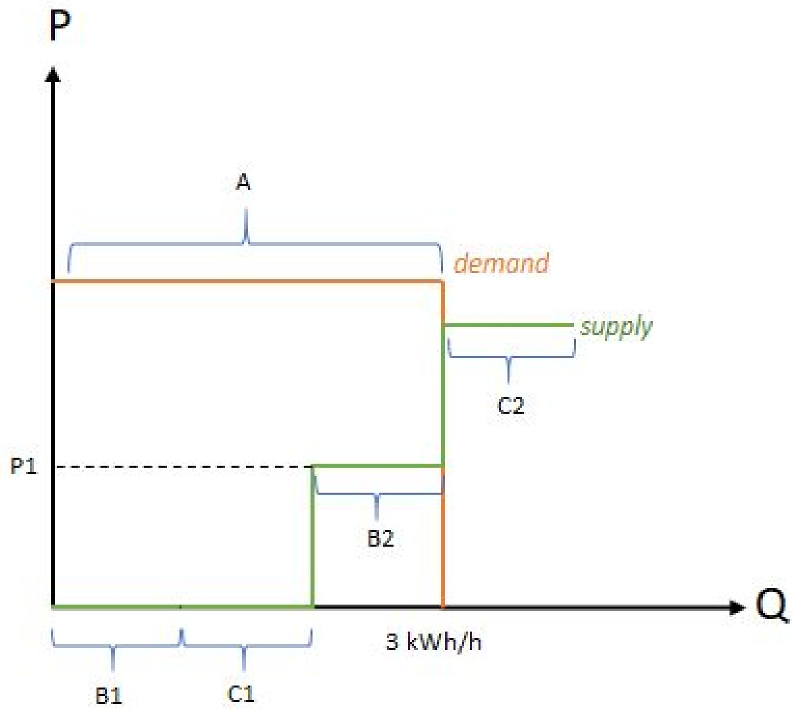

Figure 4.7. LFM member A needs three kWh/h of quotas. The demand curve represents his/her willingness to pay for quotas, based on his/her alternative cost of not having enough. B and C provide 2 kWh/h at zero cost (bids B1 and C1), and 1 kWh/h each at a positive cost (bids B2 and C2). The market clears at the cost of the lowest necessary bid, B2. A then pays B and C for three quotas, altogether a bill of 3 x P1.

Although each LFM producer has an individual net output limit (in this example, zero), attempts at exploitation could occur. In particular, a prosumer could withhold enough consumption to ensure that the supply of free quotas is exhausted, thereby forcing

[20] If production needs to be curtailed, it may be the DNO that bears the cost. The principle of the model is however the same, as long as someone has a monetary interest in ensuring that A's surplus is reduced..

purchases by those in need of quotas for a positive price. It is yet not fully clear, however, how these incentives will balance out in practice. This will require more research and potentially actual testing. Section 4.3.5. discusses some of the possible measures to mitigate the incentives for exploitation.

4.3.2.2. Flexibility trading between LFM participants to dampen loads

Equivalently to Section 4.3.2.1., a quota trading system handling high loads can be implemented where LFM participants face a price incentive structure based on a collective load, as in Backe et al. (2020). This can be considered an extension of the principles in the Norwegian regulator NVE's suggestion of "subscribed tariffs" (NVE, 2017), where consumers subscribe to a pre-agreed, individual maximum level of consumption (kWh/h) and pay a substantial extra fee for any consumption above it.

Again, let's consider market members A, B and C, but now in a high load situation. Although their individual subscription levels may differ, we could have a similar situation to the one described in the previous section: A is exceeding his/her subscription by 3 kWh/h, while B and C both are 1 kWh/h below their individually subscribed levels. Like the example in Section 4.3.2.1., B and C are willing to essentially provide two quotas in total for free. However, as A needs three quotas, B and C have to give up some consumption to free up a last quota. The pricing follows the same principle as in Section 4.3.2.1. (Figure 4.7).

When there is a surplus of quotas, the price will simply be zero, like in the model by Backe et al. (2020) where a premium only applies when the market's total consumption exceeds a threshold. This will in effect allow LFM participants more freedom in how to use energy, since they will often be able to exceed their pre-set limits at no additional cost. This may allow them to limit their consumption more easily when quotas are actually scarce. It could cause LFM participants to consume somewhat more in total, but it could also cause them to subscribe to lower consumption limits.

4.3.3. The DSO or LMO as buyer of flexibility with reservation pricing

The incentives in Sections 4.3.1. and 4.3.2. are mainly concerned with keeping the net position of the LFM within certain boundaries that do not actually reflect physical limits of the grid. However, in cases when congestion actually is about to occur, system operators will need dependable flexibility. This triggers a need for reservation pricing. Here, we discuss the basics of how a market mechanism for reservation pricing only (i.e. in the absence of activation pricing) can be set up. Using only reservation pricing is also an effective way to avoid exploitation of the kind described in the previous section and in Section 4.3.5.

A DSO would be a natural buyer of flexibility in this way. It is also conceivable that an LMO could take a similar role, but not have system operation responsibilities or handle potential congestion issues like a DSO. Rather, its responsibility would probably be to keep the net position of an LFM within an agreed, non-physical limit. In that way, it would provide a service to the DNO/DSO, or to consumers or producers who face a penalty if their collective net position crosses such a limit.

The general principles of applying reservation pricing have been described by THEMA (2016) and realized in the BQDM Program, initiated by the New York City utility ConEdison (ConEdison, 2016). The main objective addressed in these examples is the reduction of maximum demand in constrained local bottleneck situations, but the same principle can also be used when excess production is the problem. In this model, the buyer buys long-term, reservation-price based flexibility from LFM participants through auctions (THEMA, 2016; ConEdison, 2016). Auctions may be held relatively rarely; for example, THEMA (2016) suggests auctions once per year or when considered necessary. Figure 4.8 is an illustration of the basic principles.

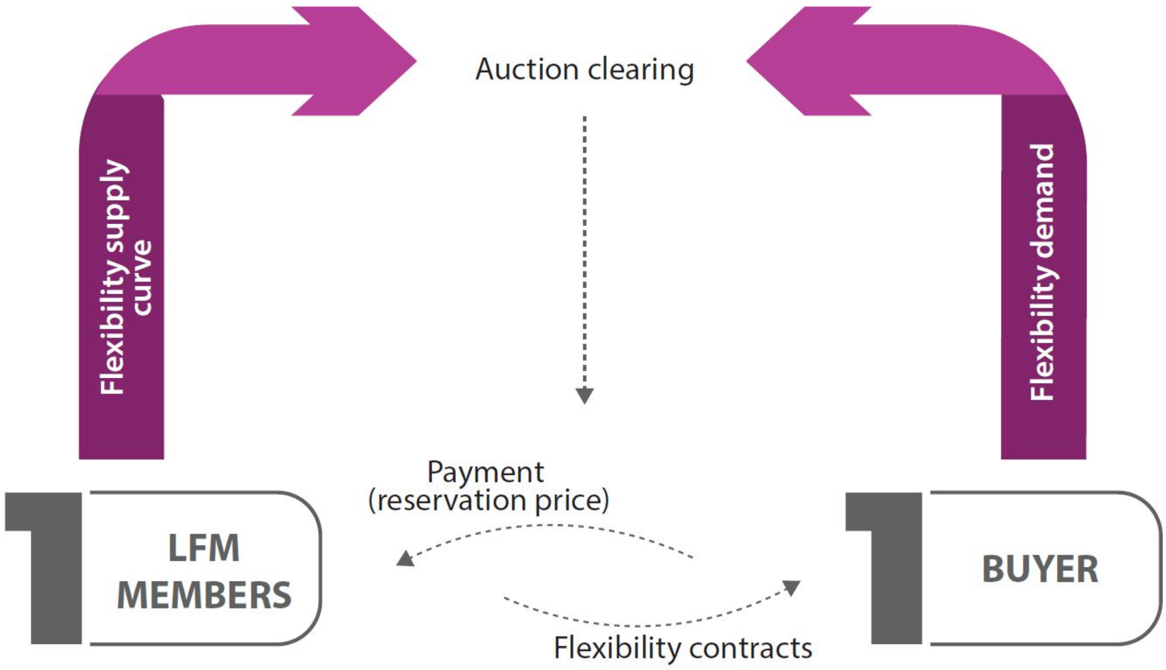

Figure 4.8. Basic structure of a model with reservation payments, based on THEMA (2016) and ConEdison (2016).

Using only reservation pricing may be less complicated compared with the other options described in this chapter. It may be easier to establish as a complement to the existing market infrastructure, and therefore face fewer barriers. For example, for the case of Norway, THEMA (2016) describe their approach as a relatively easy transition from the Norwegian "UKT" scheme. From a DSO's perspective, using only reservation pricing mitigates the risk of exploitation and potentially extreme activation prices.

The downside of using only reservation pricing is that it may not accurately represent the flexibility provider's cost of activation when the need arises. Assuming that flexibility providers optimise their consumption, non-compensated activation represents a loss for them. For example, the buyer may move the provider's consumption to a period when the wholesale spot price is higher. The reservation price a provider will accept is therefore essentially a bet on how costly non-compensated activation will be, both in terms of direct losses of energy services and as foregone opportunities for adaptation to e.g. spot prices. Hence, the flexibility provider is now the one bearing the risk. This may discourage participation and raise the necessary reservation price.

4.3.4. The DSO or LMO as a buyer of flexibility, including with activation pricing

For a system operator or LMO to also use activation pricing, it needs essentially a "price list" for flexibility activation. Like with activation pricing from capacity quotas (Section 4.3.2.), it does not matter whether consumption or production is adjusted because the net position is the relevant metric. Hence, for purchases of flexibility activation, it can be useful to illustrate both consumption bids and production bids in a single supply curve.

For example, when a DSO or LMO needs to increase the net position due to a problematically high net load (i.e. a problematically low, negative net position), a supply curve for activation prices can be illustrated as in Figure 4.9.

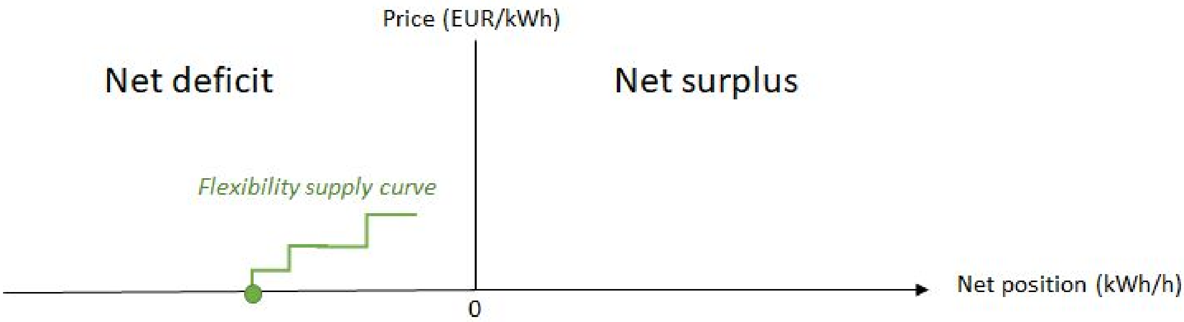

Figure 4.9. The reference net position of the local market area in a single hour is denoted by the green point. The flexibility supply curve is represented as a stacked list of activation prices and volumes.

Activation pricing introduces several challenges in this context, not least avoiding that participants try to exploit the system if they are paid to reduce their consumption (see Section 4.3.5.). However, the basic principle is fairly simple. In a negative net position for the LFM as a whole, the DSO, or potentially an LMO, may be willing to pay LFM participants to increase their net position. The buyer's willingness to pay (WTP) is captured in a demand curve, which may be very simple. Figure 4.10 shows an example where it is a hard limit, formulated as a straight vertical line up to the maximum WTP (which may be very high).

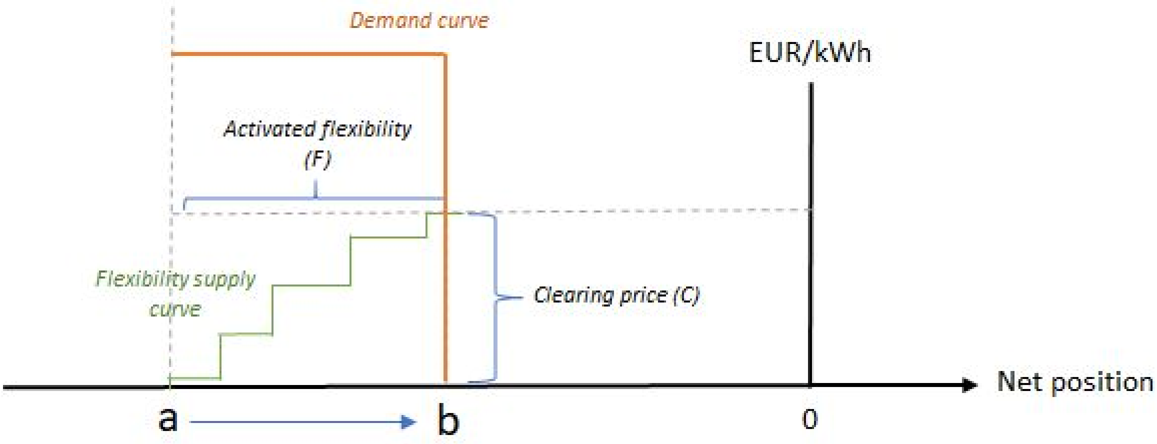

Figure 4.10. Example of a market cross where the buyer is willing to pay to shift the LFM's negative net position from point a to point b.

In Figure 4.10 the clearing price is *C*, and the reduced volume is equal to the activated flexibility *F*. With uniform pricing, the buyer's total payment to the providers would be the area *C* x *F*.

For generality, the buyer's demand curve could also be more detailed than in Figure 4.10. Figure 4.11 is an example.

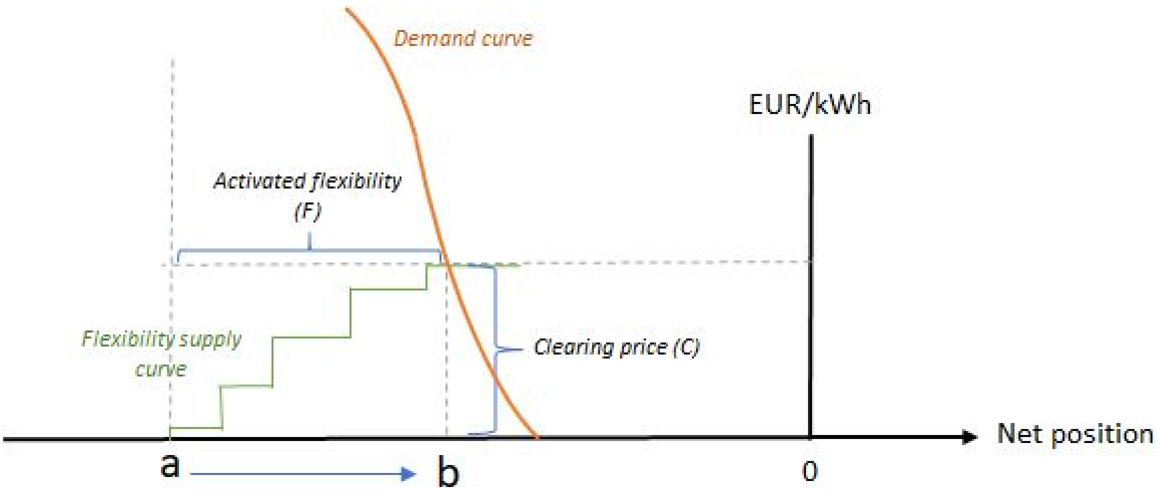

Figure 4.11. Example of a market cross where the buyer operates with a more detailed demand curve, reflecting varying willingness to pay for each level of the net position. The shape of the demand curve in this figure is an arbitrary example.

Exactly the same principle as that shown in Figures 4.10 and 4.11 can also be implemented when a DSO or LMO seeks to reduce the net position of the LFM from a problematically high positive level. In that case, the flexibility demand- and supply curve would be found in the range of a positive net position in these two diagrams.

4.3.5. Mitigation of possibilities for exploitation

One of the challenges with activation pricing, as described in Sections 4.3.2. and 4.3.4., is that it could create an incentive for exploitation. Without the right countermeasures, flexibility providers could be inclined to adjust their consumption or production in the opposite direction of what the market needs in order to have their flexible assets (i.e. those offered to the LFM) activated and compensated. This problem could be exacerbated by machine learning building control systems, which will continually search for such opportunities within the market rules. It will probably also be especially problematic in small markets; with few participants, an individual member can have a major impact on the collective load and also inflate activation prices due to a lack of competition.

There are however also reasons to believe that for some design choices, the potential for exploitation will be alleviated. First, a highly automated LFM may require that when a flexible asset is offered to an automated system that interacts with the LFM platform, its owner temporarily loses control of it. In this case, exploitation would require that a provider uses other assets and perhaps other automation systems (i.e. not participating in the LFM) to shift consumption in the "wrong" direction. Hence, this kind of exploitation entails a cost, for several reasons. First, it requires the owner to change the otherwise normal/optimal schedule of the "exploiting" asset. Second, using it for this purpose leaves it outside the LFM, where it could earn revenue. Positive correlations between the LFM's net position and the net position of the surrounding energy system may also amplify the cost of exploitation. To the extent spot prices and tariffs follow (inversely) the net position of the "external system" (e.g. of the price zone containing the LFM), it becomes expensive to shift consumption in the wrong direction. LEM incentives (Section 4.3.1.) can increase this cost even further, making it a potentially useful complement to flexibility activation pricing.

Another possible safeguard could be to add a clause in the asset owner's flexibility contract that restricts the energy consumption profile of assets not partaking in the LFM during activation. For example, the contract could specify a reservation price for an EV charger in a given period, but require that an additional activation price will be paid only if the provider's remaining consumption is kept within a contracted limit while the charger is activated by the LFM.

Generally, activation pricing is less risky when the driving force for trade is the reduction of fees (see Section 4.3.2.) than when a system operator buys flexibility to avoid actual congestion (see Section 4.3.4.). In the former case, the potential for exploitation is limited by the potential buyers' alternative of simply paying the extra fee. In the latter case, however, the willingness to pay can be extremely high, which could cause prosumers to name very high and unpredictable activation prices. To manage this risk, a system operator may decide to e.g. cap or fix activation prices, or only use reservation pricing (Section 4.3.3).

Incentives to exploit activation pricing can be difficult to fully avoid, and there may be no "perfect" solution. The complexity of the market incentives also suggest that there may be other, undiscovered possibilities not described in this report. Therefore, continued research and evaluation will be an important part of the calibration of the LFMs throughout the +CityxChange project period.

4.4. Allocation of roles and responsibilities

Besides the choice of price-setting mechanisms, the LFM design also needs to consider which roles the market requires and who should hold them. This section presents several alternatives.

Clearly, there exists a very wide range of options. However, the range is somewhat narrowed by a key hypothesis in this report, which is that an LFM will be an add-on to existing energy markets. In practice, this means that an LFM is not meant as a separate wholesale price zone or node, and that LFM participants can retain a normal relationship with an energy retailer and a DNO.

4.4.1. Roles and institutions

The +CityxChange deliverable 2.1. (+CityxChange, 2019) identified that two of the likely roles in a local market would be the system operator and the market operator.

A natural institution taking on a system operation role at the local level is the distribution system operator (DSO). In an LFM, a DSO could be a buyer of system services from the local flexibility providers. It could also operate a market platform.

The **market operator** role is primarily to facilitate the local market in a neutral manner. However, we find it useful to distinguish between several aspects of market operation. We have identified several possible tasks:

1. **Market platform operation.** While the market platform may be highly automated, an institution needs to operate and oversee it.
2. **Incentivising internal trading.** Current grid tariffs and energy prices do not typically incentivise trade between the participants in the LFM (internal trading). The necessary incentives may be introduced by a DNO/DSO or LMO (Sections 4.3.1. and 4.3.2.). To the extent this would require payments or discounts to the LFM participants, the LMO would need to be contracted and receive its income from those who benefit from the local flexibility.
3. **Prosumer contract counterparty.** The entity with which LFM prosumers sign contracts to supply flexibility. This would typically be an ESCO, an aggregator, a retailer, and/or the institution that operates the market platform.
4. **Flexibility request coordination.** Ensuring that requests for flexibility from the DSO, internal trading, TSOs and BRPs are coordinated and do not cause harm, neither at a local nor at the wider level.

5. **Disturbance neutrality provider.** As described in Section 5.2, disturbance neutrality is an obligation of a Community Grid System.

The system operation role and the various market operation subroles can be allocated among institutions in many different ways, and presenting an exhaustive list here would be too extensive. In the following, we therefore illustrate only some selected examples.

4.4.2. DSO-operated LFMs

Figure 4.12 is an example of purely DSO-run market. Here, the DSO (naturally) holds a local system operation role, but also runs the market platform where it buys flexibility from the LFM participants and signs contracts with flexibility providers. By themselves, these roles operated by the DSO would classify this model as similar to that suggested by THEMA (2016). Additionally, however, a DSO could introduce incentives for internal trading in the LFM, such as special tariffs adjustments that enable trading mechanisms like those described in Sections 4.3.1 and 4.3.2. If so, the platform could also handle trade between LFM prosumers. The DSO would also need to be coordinated with "external" flexibility requests from e.g. aggregators selling services to BRPs or the TSO.

Figure 4.12. Example of a market where the DSO takes on all local market roles.

4.4.3. Market operation by an LMO

The DSO would be a natural holder of the roles of local system operator and of flexibility request coordination, and could also be the introducer of internal trading incentives (through grid tariffs) although an LMO might also introduce equivalent incentives. However, in many cases the role of being a prosumer contract counterparty could be more naturally held by an intermediary like e.g. an ESCO, retailer or another third party like a LMO. Moreover, a third party could operate the market platform, where the DSO would be a buyer of system services (USEF, 2018). In the following, we will refer to this third party as an LMO. Hence, a different model could be organised as illustrated in Figure 4.13:

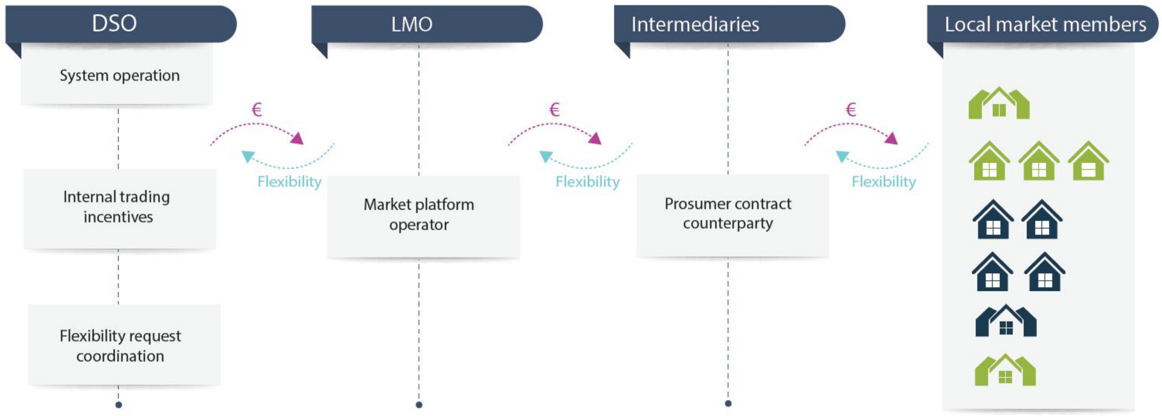

Figure 4.13. Alternative allocation of roles, with an LMO operating the market platform and intermediaries handling flexibility contracts with prosumers.

Conceivably, the LMO operating the market platform could also sign flexibility contracts directly with asset owners, without an intermediary. A variant including this option is illustrated in Figure 4.14.

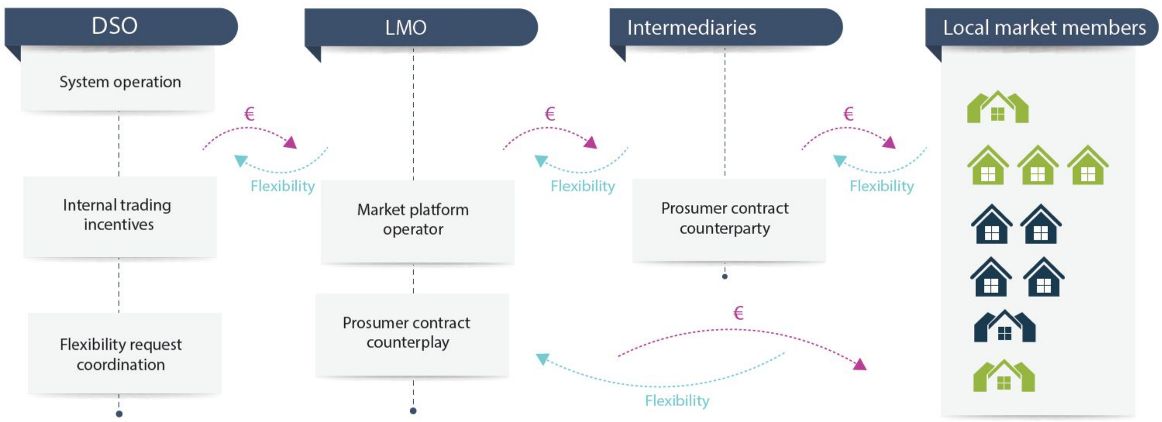

Figure 4.14. Alternative where the LMO also sign flexibility contracts directly with asset owners

4.5. A relationship map for flexibility market design

The last sections outlined both general principles for LFMs (Section 4.1.) as well as various design options (Sections 4.2.-4.4.). The choice between design options is expected to depend on local conditions that may differ between locations in Europe. These conditions may reflect the current state of the energy system and infrastructure, but also what can be expected over the next decade or so. This section provides an overview of likely influential conditions and discusses how these can guide design choices.

Below, we list conditions to consider, and the likely implications they will have for LFM design. The section ends with a set of illustrations of how the conditions and design choices are related (Figures 4.15a-c).

1. **Intermittent microgeneration, e.g. rooftop solar PV.** Some European countries have good solar resources and a potential for substantial volumes of rooftop PV. This suggests a need for market mechanisms to absorb surplus energy (see Section 4.3.). It may also suggest a need for a Community Grid System with a grid stabiliser to maintain stability if the volume of microgeneration is difficult for the DSO to handle or connect. This may be the case if the DSO has many prosumers to manage, or if the DSO role is not far developed. However, the problem of excessive surplus solar generation is not equally pronounced everywhere.
2. **Electric vehicle penetration or other high-load electrical equipment.** Countries differ in their current state and future plans for electric vehicles. High ambitions for EVs suggest that capacity in the LV grid can become a major challenge. In this case, there is a potential need for market mechanisms for peak load shaving (see Section 4.3.), combined with local system operation (DSO) capabilities. Besides EVs, other kinds of high-load equipment can also exacerbate peak electrical loads.
3. **Sector coupling possibilities in the LFM area.** As discussed in Chapter 3, shifting between energy carriers can be a major way to prevent congestion. Hence, cities and districts with the infrastructure for such switching possibilities may have a significant source of flexibility available. This suggests that the integration of these resources should be a priority in the market design and in LFM member recruitment. In particular, whole building control systems become more valuable. However, future plans need to be considered, as decarbonisation strategies could mean that e.g. gas fueling and district heating systems eventually will be replaced with electricity.
4. **Existing low-carbon flexibility resources.** Some countries may have relatively cheap low-carbon flexibility available, e.g. hydropower. This may entail that flexibility for system-wide balancing is relatively cheap, so that demand-side flexibility is less profitable. If so, LFM participants become relatively more dependent on the revenue from the LFM's ability to prevent local problems like distribution grid congestion. In countries without such resources, however, it is probably more important that the LFM design facilitates attractive access to "external" markets for the LFM participants.

5. **DSO role maturity.** Some LFM designs require a DSO to act as a buyer of flexibility. However, DSO capabilities are currently being developed (Colle, Micallef, Legg, & Horstead, 2019). When sufficient capabilities are not in place or expected soon, LFM design may need to focus more on the complementary role LFMs can take in collaboration with the DNO/DSO.
6. **Number of prosumers per DSO.** Large numbers of small-scale producers may be challenging to handle for a single DSO. In this case, the concept of the Community Grid System with its own grid stabiliser (see Section 5.2) can be an attractive approach.
7. **Market size (except for testing and pilot purposes).** A small market size is a challenge for several LFM models. While not necessarily a problem for testing purposes like in the +CityxChange project, the longer-term scalability of LEMs and especially LFMs may depend on sufficient market size. Especially, LFM mechanisms intended for congestion management (Sections 4.3.3. and 4.3.4.) may be considered too unreliable if the LFM is too small. Still, internal trading (Sections 4.3.1. and 4.3.2.) could in itself be valuable if the problem of small economies of scale can be overcome.
8. **Non-professional and/or small-scale participants.** LFM designs should consider which kinds of prosumers it wants to recruit. Households and small businesses are likely to require far simpler contracts and less frequent interaction with the market than larger, more "professional" actors like e.g. industrial buildings. Therefore, an LFM targeting small-scale prosumers may need to ensure that prosumer contract counterparties that can provide such contracts are enabled easy access to the market. As outlined in Section 4.4.3., the prosumer contract counterparty role can be covered both by the operator of the market platform and by intermediaries like retailers and ESCOs.
9. **Severity of congestion problems.** If congestion problems are not currently present and are not expected for a long time, it may not be worthwhile implementing a market solution centered on DSOs buying flexibility for congestion management (Sections 4.3.3. and 4.3.4.). However, if future congestion problems are expected given plausible scenarios, LEMs and LFMs that stimulate internal trading to dampen loads (Sections 4.3.1.2. and 4.3.2.2.) can potentially be useful instruments to slow the growth in peak loads and thus postpone grid upgrades.
10. **Political principle of equalised rather than cost-reflective grid tariffs.** Some countries may use payments for grid infrastructure as a means of economic distribution.[21] This increases the likelihood that incentives for internal energy and flexibility trading may have to be voluntary and to be implemented by a third party LMO rather than a DNO/DSO.
11. **Political principle of stimulating energy saving and/or local self-generation through volumetric grid tariffs and taxes.** This implies that it may be difficult to restructure DNO grid tariffs or equivalent price incentives towards incentives that facilitate internal energy- and flexibility trading. If so, this also increases the probability that incentives for internal energy- and flexibility trading must be voluntary and implemented by a third party LMO rather than a DNO/DSO.

[21] For example, in Norway, there is an ongoing debate regarding equalised grid tariffs (Oslo Economics, 2019; NVE, 2019a).

12. **Willingness to pay extra for certified, locally produced energy.** In this case, the LFM must include an option for prosumers to state how much more they are willing to pay for this (see Section 4.3.1.1).

Figures 4.15a, 4.15b, and 4.15c below summarise the relationships between conditions (left) and design choices (right). These are drawn with polarities from the causal loop method (see e.g. Sterman (2000)) where a plus sign means that the source variable (condition in this case) influences the variable it points to (design choice or intermediary variable in this case) positively. Minuses signify the opposite. In our context, a plus sign means that the stronger the state of the condition (green boxes, left side), the more favorable the design choice (blue boxes, right side) looks. Grey boxes are intermediary variables. It should be kept in mind that this mapping only rarely denotes a condition as an absolute requirement for a design choice. Rather, it shows how a condition is expected to increase the attractiveness of a design choice, all else equal.

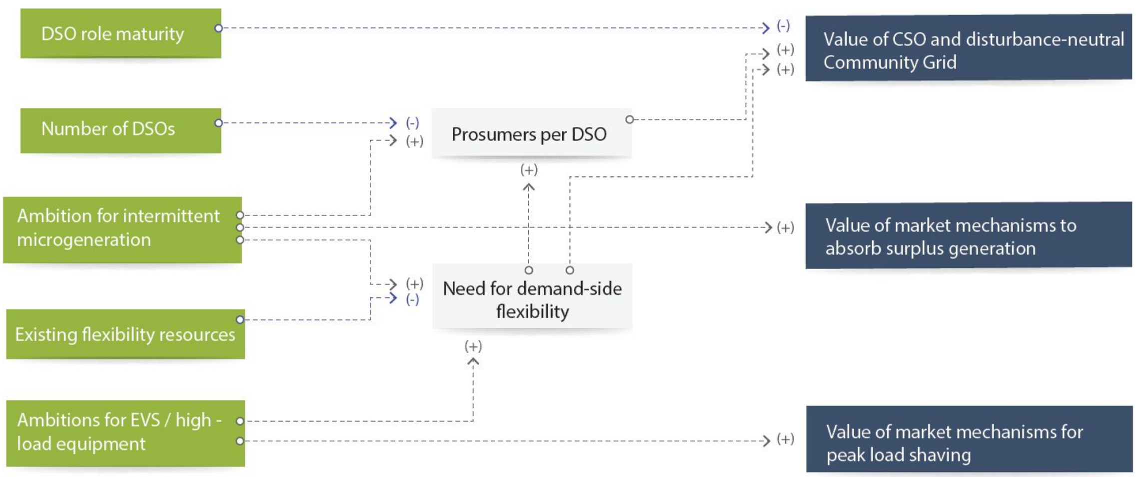

Figure 4.15a. Relationship map (1) of conditions and design choices.

In Figure 4.15a, the value of an LFM design with a CSO, Community Grid System, and Grid Stabiliser is reduced by DSO role maturity and increases with the number of prosumers per DSO. In turn, this depends on the ambitions for renewable (chiefly solar) microgeneration and the need for demand side flexibility for balancing. This is because demand response for balancing can in some cases create large local generation surpluses. The need for demand response for balancing is in itself affected positively by the ambitions for intermittent microgeneration and ambitions for electric vehicles (EV) and other high-load equipment, but reduced by the extent of existing flexibility resources. Countries with a large capacity for dispatchable hydropower (e.g. Norway) would be an example of the latter. The ambitions for EVs and similar equipment also naturally increase the value of market mechanisms for peak load reductions.

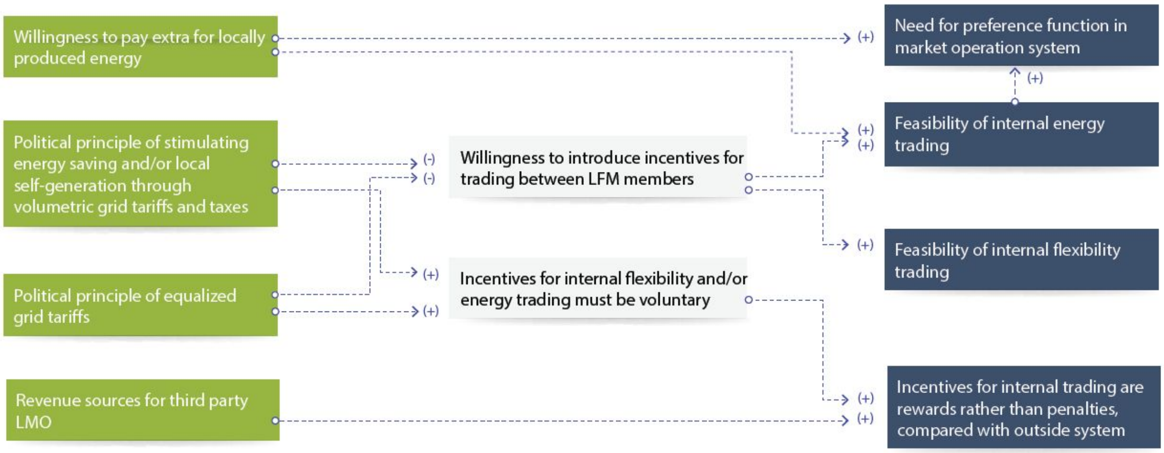

Figure 4.15b. Relationship map (2) of conditions and design choices.

In Figure 4.15b, the willingness consumers have to pay a premium for locally produced and/or renewable energy implies a higher importance of programming a market mechanism where these preferences can be entered (preference function); see Section 4.3.1.1. It also increases the value of internal energy trading, which is a prerequisite for the preference function. Monetary incentives for internal trading have to be introduced, but the willingness to provide such incentives may be limited by political principles of equal grid tariffs (i.e. not wanting to give the LFM special treatment even if it would save total system costs) or the concern that such incentives, to the extent they replace existing volumetric components of grid tariffs, will reduce the incentive for energy efficiency and self-generation.[22] These factors make it more likely that incentives for internal trading would have to be voluntary or formulated as rewards rather than penalties, although the underlying political principles could prevent this also. As mentioned earlier, however, the LFM could be a response to a DNO's requirements to keep the net load or generation of assets within a certain range in order to allow them to be connected (with the alternative being e.g a fee paid by the asset owners). This approach is not necessarily in conflict with the political principles for grid tariffs mentioned above.

[22] In Norway, such an argument has for example been made by the homeowners' association (Huseiernes Landsforbund, 2018).

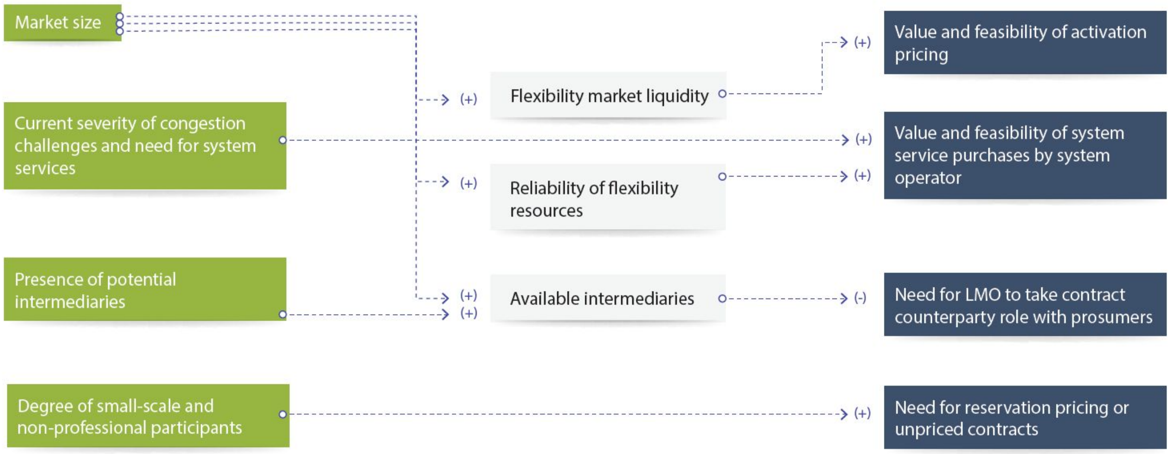

Figure 4.15c. Relationship map (3) of conditions and design choices.

In Figure 4.15c, the LFM size increases the LFM's liquidity as well as the reliability of flexibility resources (not having to depend on just a few assets). It probably also means that more intermediaries (ESCOs, aggregators, retailers, etc.) will find it attractive to trade with the LFM platform, which reduces the LMO's need to sign contracts directly with prosumers. Liquidity makes activation pricing easier since it reduces the potential for market power. A market that facilitates system service purchases by the DSO is made more feasible by the reliability of assets, which is important when congestion problems are serious. If the market is implemented in areas with many small-scale, non-professional (usually residential) participants, there is a need for relatively simple contracts like unpriced contracts or reservation pricing (see Section 4.2.2.2.).

5 Flexibility market design: Trondheim and Limerick as cases

5.1. Introduction

This part focuses on two examples of how the design tool in Chapter 4 can be applied: Limerick and Trondheim, the two +CityxChange Lighthouse cities. In these descriptions we note both what the country-specific conditions are likely to imply in each case for LFM design in general in Ireland and Norway, and which ambitions seem natural to recommend for the selected test areas within the +CityxChange project. These perspectives may be somewhat different. Also, it is worth noting that the practical feasibility of many suggestions will depend on agreement from regulatory bodies, the DNO/DSO in each case, and flexibility asset owners. We expect that the actual project implementation will contain several adjustments to what is described in this report. After going through the cases of Limerick (Section 5.2.) and Trondheim (Section 5.3.), we also briefly summarise relevant characteristics of the countries of the +CityxChange Fellow Cities (FCs) (Section 5.4.). However, for the FCs, we do not discuss what the country conditions are likely to imply for LFM design.

5.2. The case of Limerick

5.2.1. Limerick: Background and overview

In Ireland, there is a major challenge to increase the penetration of renewable resources onto the grid. Ireland being an island, has lower grid inertia to manage high penetration of intermittent renewable sources. A large percentage of Ireland's generation is provided by wind energy. There are significant challenges to managing the high capacity of the intermittent wind. Therefore, there is a need to investigate alternative options for increasing RES penetration. This has resulted in a shift in focus towards the energy transition, which moves away from the practice of developing large remote power plants towards the integration of distributed renewable resources in close proximity to consumers. This energy transition has numerous benefits for the communities. However, this increase in local production interferes with the stable delivery of electricity to nearby consumers.

There are also a number of motivations for developing an LFM that are specific to Limerick City. Firstly, the integration of an LFM trading platform strongly aligns with Limerick's 2030 vision for becoming a leading digital city. A key technical challenge of the platform development is overcoming issues surrounding data transmission and sharing. Limerick's digitisation plan has resulted in digital integrations such as a Smart City LoRa network and API enabled infrastructure. These digital technologies will assist in the integration of an LFM trading platform in Limerick City. The +CityxChange project that incorporates the design of an LFM platform will greatly assist in Limerick City becoming a leader in Smart city digital innovation. Secondly, in the near future Limerick City will be facing major grid stability issues, due to the Irish government accelerating deployment of electric vehicles, coupled with the fact that nZEB (nearly Zero Energy Building, a building standard concerned with energy consumption) is now law in Ireland. Also, unlike other countries where there is a number of Network Operators, in Ireland there is only one DSO, so therefore it would be very difficult to manage the stability of the whole network. Hence, there is an interest in the MPOWER disturbance neutrality trading solution which requires the establishment of Local Flexibility Markets. Lastly, Limerick City has a very low penetration of renewable energy based generators. MPOWER is providing community grid members an alternative route to connecting generators, rather than using the DSO's current inflexible stance on Renewable Energy Sources (RES) integration, which is effectively causing a bottleneck in the integration of RES. The new trading solution is of great interest to many community stakeholders in Limerick City.

5.2.2. Limerick: Market design approach

The following section discusses how the market design tool (Chapter 4) can be applied in a Limerick case. The first section summarises conditions and design choice options from Chapter 4 in a table. The key design decisions are discussed in more detail in the market design approach Section 5.2.2.3.

Condition	**Conditions in Limerick**	**Market Design Implications**
A high need for intermittent microgeneration, e.g. rooftop solar PV.	Limerick has a high potential for microgeneration market growth, particularly solar PV resources.	Market mechanisms to absorb surplus solar generation in the LV grid is high priority for the Irish Authorities
Number of prosumers per electricity DSO, maturity of DSO role.	Ireland has a high customer/DSO ratio. Unlike other European countries where there are a large number of network operators, it would be very difficult for a single operator to manage the stability of the whole network.	There is a high suitability for a CSO solution based on the outlined conditions.

High electric vehicle penetration or other high-load electrical equipment.	Ireland currently does not have high electric vehicle penetration. However, an ambitious programme to increase penetration of EV-charger on the Distribution Network is being developed by the Irish Authorities	As a result, market mechanisms to handle peak loads on the distribution network will shortly have to be introduced.
Potential market size (except for testing and pilot purposes).	MPOWERs community solution can be adapted in both urban and rural populations. MPOWER can provide a solution for both residential and commercial installers that want to sweat their assets. Currently, a major limitation of the market is the number of Energy & flexible Assets in Limerick. However, there are a number of new government incentives for microgeneration. In the near future, through the nZEB standard there will also be increased network penetration of microgeneration. A major challenge is attracting and onboarding of participants.	It is intended that MPOWER, a CSO entity will act as an enabler for CEC's communities with their onboarding process of participants. MPOWER would not have the resources to effectively onboard a large number of prosumers. This would be a far more effective method to reach critical mass that is required to make their solution commercially viable.
Severity of congestion problems.	Currently Limerick City has a stable power grid where power quality is not a concern. In the near future, there is concern that with the nZEB standard, the increased network penetration of microgeneration and EV chargers will cause the grid to have major stability issues. However in the short term, there is no major concern.	There will be a requirement in the near future for solutions such as internal flexibility trading.

Sector coupling possibilities.	Compared with European neighbours, Ireland utilises a relatively low proportion of electricity for heating. It mostly uses gas for residential and office buildings. Albeit the Limerick district is an exception whereby there are many Georgian Buildings that use a relatively higher percentage of electric heating . In Ireland and in the Limerick district there is no well-established district heating system which can be used for sector coupling.	Sector coupling possibilities are quite limited in Limerick city. Through +CityxChange work package 4.6, there will be further investigation of integration of CHP for district heating and investigation of electric heating as a source of flexibility.
Willingness to pay extra for local, renewable energy.	Ireland has a high carbon emissions intensity. Addressing this issue is high on the Authorities agenda. However, It is uncertain whether the general public will pay higher for local renewable energy.	MPOWER Community based flexibility solution will greatly rely on government incentive support.
Incentives for internal flexibility and/or energy trading must be voluntary.	As part of the +CityxChange project, MPOWER are in negotiations with the CRU (Commission of Regulation for Utilities) for the development of new support mechanisms for Energy Communities.	For a community LEM/LFM to be competitive, the market design strategy is dependent on fair energy community support mechanisms.

Table 5.1. Possible ways to apply the proposed framework from Chapter 4 in Limerick.

5.2.2.1 MPOWER CSO Core Principles

The MPOWER flexibility solution to be tested in +CityxChange in Limerick is based on the principle of a Community Grid System (CGS) that is disturbance neutral. Many of these concepts are based on the initial concept development as outlined in submission paper to the Irish Energy Regulator (CRU) by Stewart (2015).

MPOWER's flexibility solution involves instantaneous power matching of local consumption and local production. One of the key mechanisms to achieving this solution is by implementing grid flexibility, whereby consumers can increase or decrease their consumption to maintain real time system balancing. By decreasing the distance between consumer and producer, MPOWER is providing a solution that significantly reduces distribution losses and avoids capacity upgrades. Furthermore, MPOWER's solution will enable higher penetration of RES on to the distribution grid.

MPOWER’s solution to the challenges of the energy transition is to create Ireland’s first CSO (Community System Operator). The CSO is a legal identity which manages a CGS. A CGS comprises of participants that provide disturbance neutrality. Participants may undertake the role of energy producers, consumers, and flexible consumers. In many cases, the participant can undertake multiple roles. A recent EU Directive clearly outlines the operation and criteria of a Citizen Energy Community (CEC) (European Parliament & Council of the European Union, 2019) A CGS is a CEC (Citizen Energy Community) or multiple of CECs that also provides the service of disturbance neutrality to the DSO.

Initially, MPOWER’s will focus on designing the CSO to function as the CGS local Energy and Flexibility trading operator, whilst upholding the principle of disturbance neutrality. In the future, MPOWER aims to further develop the CSO solution to provide services such as local power quality mitigation services for the DSO and system balancing services for TSO. Through the +CityxChange project, MPOWER aims to meet their objectives by undertaking live power system and trading demonstrations, achieving required regulator support and testing the CGS participant uptake.

One of the core principles behind the MPOWER trading mechanism is the concept of disturbance neutrality. In the +CityxChange project, disturbance neutrality entails the condition that the net electric power output of a CGS is zero or less. MPOWER plans to develop the concept of disturbance neutrality to include Power Quality Mitigation. However, that is beyond the scope of the CityxChange project.

Another key part of the MPOWER solution is the Community Grids Stabilizer. The Community Grids Stabiliser functions as an automated regulator, absorbing or injecting power in times when contracted participants are unable or unwilling to respond to the needs of the CGS. The Community Grids Stabiliser also provides flexibility dedicated exclusively to the MPOWER enerXchange platform, the virtual platform that facilitates local trading between CGS participants in the market.

5.2.2.2 Overview of Trading Model Options

There are several trading models presented in this report. It is envisaged that the trading models that will be tested in the MPOWER platform as part of +CityxChange in Limerick City are outlined in the following paragraphs.

However, this paragraph will firstly outline a number of presented trading practices that will not be incorporated in the +CityxChange project in Limerick. In Sections 4.3.3. and 4.3.4., it presents a flexibility trading model for a DSO to become a buyer of flexibility through reservation or activation pricing or both. The Irish DSO system services are currently in their infancy. Currently, Limerick City has a stable power grid whereby power quality is not a concern. So, therefore it is not envisioned there will be requests from DSO for flexibility to deal with bottlenecks. As a result, as part of the +CityxChange platform MPOWER will not consider CGS- DSO trading.

For internal energy trading, we have identified a basic option that would align with a community based system. In Section 4.3.1.1., it presents a model which is entitled "LEM mechanisms to absorb excess surplus energy". The model's approach to the challenge to absorb temporary local energy surplus is to lower its price. In short, consumers will get local energy lower than the retail price. We considered a number of factors in choosing the LEM price for the consumer as the main driver. Firstly, the Irish wholesale Electricity price has been increasing annually at an alarming rate and cost reduction would be a driver to attract prosumer interest. In a report published by the CRU (2019), the average wholesale electricity price (System Marginal Price, SMP) between 2017 to 2019 is 16% higher. Furthermore, MPOWER's trading solution proposes to reduce the enormous cost of the Network reinforcements whilst delivering higher RES penetrations. Currently, MPOWER is in discussions with CRU to develop new support mechanisms for Energy Community Trading. The model will aid with balancing the community grid net position, which is required for MPOWER's design principle of disturbance neutrality whereby the net position is required to be zero or less. However, the model is simplistic and there are a number of considerations that have to be developed further, such as the allocation of discounts or P2P auctions between the net consumers. It is envisioned that such considerations will be overcome in the trading design testing process in task 2.3. Lastly, a major barrier to the creation of the local energy market is the high dependence on fair energy community support mechanisms from the Irish Authorities. This will be explored in task 4.4.

For the internal flexibility trading, we are in agreement with the recommendations of the model outlined in Section 4.3.2.1. The proposed model is very similar to the internal energy trading model; it works on the principle of monitoring a net position. Also, in implementing this internal flexibility trading model along with the Community Grid Stabiliser, the net position will never exceed the limit of zero to meet the condition of disturbance neutrality. It's key that our platform implements models that manage disturbance neutrality.

Lastly, there are other market design considerations that have been identified from following the process in Section 4.5. As part of the Market Design, it's critical to have baseload generation from a RES plant. This will provide a stable LEM market. Likewise, there is a requirement to have a similar baseline flexible capacity for the LFM. System resilience is a critical feature in the design of a disturbance neutral Platform. A major barrier to the realisation of developing a LFM/LEM solution is the availability of assets and participants.

5.3. The case of Trondheim

5.3.1. Trondheim: Background and overview

In general, Norway has a strong grid compared with other European countries. This is because the grid is built to manage electrical heating of buildings, contrary to what is normal in the rest of Europe. The consumption of electricity in Norway in a normal year is about 130 TWh in a country with 5 million inhabitants. The consumption of electricity per household is almost the highest in the world.

Nevertheless, Norway will face problems in the future. In order to satisfy the demand for reduction of greenhouse gases Norway has to do a lot more than other countries within the transportation sector. This is because Norway already has nearly carbon-free production of electricity and cannot reduce emissions in that sector. The consequence of this is a very strong electrification of transport in the coming years, and the demand for charging of EVs will lead to challenges for the grid and its capacity. The charging of EVs will mainly be done in the low voltage grid and often within business areas like the designated areas for PEBs in Trondheim – Brattøra and Sluppen. Electrification of other transport, like buses, trains, boats, and so on, will add to the challenge.

Another problem will be the general expansion and densification of cities which will lead to expensive reinforcement of the grid and replacement of transformers. In cities like Trondheim, where you often encounter requirements for archaeological excavations when the cables in the ground need to be replaced, it can be extra expensive.

Although Norway is far north, there is a major increase in investments in solar cells which also eventually may create problems in the grid that could be solved by flexibility markets. The combination of increasing solar capacity and the general demand in the future of Near-Zero-Energy Buildings may eventually lead to a need for new ways to manage the grid locally. In general, local charging and solar PV could lead to increased demand for reactive power and problems with over harmonic oscillations. Local system services could ease these issues.

In Norway, as in other countries, flexibility in power consumption is underutilised. The combination of more renewables within local areas and lack of utilization of flexibility will be of great interest in the work of +CityxChange.

5.3.2. Trondheim: LFM design approach

The following section discusses how the market design tool (Chapter 4) could be applied in a Norwegian context. We find that the conditions applying to Norway in general also are closely descriptive of Trondheim. However, what the Norwegian conditions suggest for LFM design in general does not necessarily fully overlap with what we suggest testing in Trondheim in +CityxChange, which has a European perspective.

The first section summarises conditions and design choice options from Chapter 4 in a table. The key design decisions are discussed in more detail in the sections after.

5.3.2.1. Overview of conditions and design choice implications

Like in the example for Limerick, the following table is an example of how the framework in Chapter 4 can be applied to the case of Trondheim/Norway, in a long-term perspective.

Conditions	State of conditions in Trondheim/Norway	Likely iImplications for LFM design
A high need for intermittent microgeneration, e.g. rooftop solar PV	Currently less than in most other European countries	Market mechanisms to absorb surplus solar generation in the LV grid are currently not the highest priority
High electric vehicle penetration or other high-load electrical equipment.	Ambitious incentive program for EVs	Market mechanisms to handle peak loads are a priority
Existing flexibility resources	Through its hydropower resources, carbon-free flexibility is very good compared with most of Europe	The need for low-carbon flexibility through e.g. batteries, demand response, and power-to-gas is lower than in most of Europe, especially for system-wide balancing. However, the hydropower resources cannot necessarily help with local congestion issues. This implies that compared with other countries, incentives for investments in demand-side flexibility may have to be motivated by local concerns (e.g. LV network congestion avoidance) to a larger degree.
Sector coupling possibilities	Norway is highly electrified, using very little natural gas in residential and office buildings. Trondheim, as many of the larger cities, has a district heating system with a high degree of flexible and renewable production including flexible use of electricity.	The presence of district heating systems in the larger cities suggests that LFMs may be more effective there than in other locations, all else equal.

Number of prosumers per electricity DSO, DSO role maturity	Norway has more than 100 electricity DNOs, however, their sizes vary significantly. DSO capabilities are currently being developed (Energi Norge, 2018a). The relatively low need for solar microgeneration and the very flexible existing hydropower capacity suggests that the need for prosumers (including flexible consumers) may be less than in most of Europe.	The need for Community Grid Systems currently seems less than in e.g. Ireland. However, this could change in the longer term.
Willingness to introduce incentives for energy and flexibility trading between LFM participants	Uncertain. For the +CityxChange pilot, this will be explored in Task 5.4.	Uncertain.
Potential market size (except for testing and pilot purposes).	Norway's population is spread out over a large geographical area, and there is just a handful of cities with more than 100 000 people. It also has more than 100 DNOs. Norwegian electricity consumption per person is however very high by European standards.	Beyond the pilot projects in +CityxChange, platforms covering large geographical areas may be more important than in other countries.
Primarily non-professional and/or small-scale participants.	Today, the incentives for flexibility are probably highest in commercial and industrial buildings, which pay peak load-based tariffs and may also have larger sector coupling flexibility than residential buildings.	LFMs may have more success targeting commercial and industrial buildings, perhaps especially in cities with district heating. Besides a higher potential for flexibility, the contract design and incentive structure for internal trading can also be more advanced than for residential participants, and market involvement will likely be higher.
Severity of congestion problems	Currently most of the electrical distribution grid has sufficient capacity. However, it may be considered too expensive to secure the same level of spare capacity in the future grid (Energi Norge, 2018a).	May be relatively conducive to market solutions that attempt to slow the growth in the need for grid capacity, such as internal flexibility trading. However, the need for congestion management may increase (Energi Norge, 2018a), which suggests that market mechanisms for this purpose also eventually will be needed.

Political principle of equalised rather than cost-reflective grid tariffs	Ongoing political debate about the equalisation of grid tariffs between regions, especially between rural and urban areas. (see e.g. Oslo Economics (2019) and NVE (2019a))	Potentially a challenge for the willingness to implement internal trading through special incentives where prices are different from those outside the LFM. Voluntary schemes implemented by LMOs, including schemes designed to adhere to connection requirements, may be comparatively more important.
Political principle of stimulating energy saving and/or local self-generation through volumetric grid tariffs and taxes	Commercial and industrial consumers usually already pay only a small volumetric component. The regulator NVE wants to reduce the volumetric component and increase the component dependent on maximum load also for households (NVE, 2017). However, this is strongly opposed by interest groups like e.g. the homeowner's association (Huseiernes Landsforbund, 2018). It is currently unclear how the issue will be treated politically.	Market models for internal flexibility trading could be resisted if the incentives include a replacement of existing volumetric tariffs. In that case, LFMs may be easier to implement among large commercial and industrial participants.
Willingness to pay extra for local, renewable energy	Probably smaller in Norway than in most of Europe, due to a nearly CO_2-free electricity supply already.	Suggests lower priority on market mechanisms that incorporate the particular value of local energy.

Table 5.2. Conditions and design choice implications in Norway.

5.3.2.2. Potential for internal flexibility trading in Norway/Trondheim

The Norwegian regulator NVE currently plans a transition away from energy-based (volumetric) tariffs to a system more based on peak loads for household consumers (large, commercial customers already face such tariffs) (NVE, 2017). This should in principle create more opportunities for LFMs that include internal energy- and flexibility trading. However, the exact shape of future tariffs is not yet decided, and may differ somewhat between DNO areas.[23] Not all tariff structures will by themselves be conducive to internal trading (trading between LFM participants), which is an ambition in the +CityxChange project.

In particular, internal flexibility trading systems built around the tariffs currently applied to large, commercial customers in Norway would face several challenges. These tariffs apply a

[23] By itself, NVE's proposed scheme (NVE, 2017) would add a penalty fee whenever a consumer's electrical consumption exceeds a pre-agreed, individually subscribed level. NVE's proposal was however resisted by various stakeholders and eventually abandoned (Energi Norge, 2018b) (partly for reasons that the trading mechanism in Section 4.3.2. would mitigate). A new NVE proposal for grid tariffs is expected soon (NVE, 2019b).

fee based on the maximum consumption hour (kWh/h) within a period, like a month. Based on this scheme, one could intuitively imagine an LFM mechanism where participants could pay others to limit their consumption instead of limiting their own. For example, the LFM could pool all the participants' loads and calculate a tariff based on their collective peak load per month, the costs of which would then be distributed among the participants in some way. This would correspond closely to the scheme by Backe et al. (2020) and what is described in Section 4.3.1.2., but with the difference that the threshold level above which prices would rise would be a floating value determined by the latest, within-period collective maximum load. However, as discussed in Section 4.3.1.2., flexibility trading built around this general scheme could create an incentive for individuals to increase the load so that they are paid to reduce it (assuming activation pricing). Another alternative could be that each member would be allowed to treat one's own current within-period maximum as a floating, personal threshold that could be bypassed through buying "quotas" from other participants (see Section 4.3.2.2). However, this could generate an incentive to withhold quotas at critical times, in order to get other participants to raise their own threshold and thus increase the supply of free quotas for later.

We find that if the ambition is to test internal flexibility trading with activation pricing, a market model built around the principles described in Section 4.3.2 currently seems the most promising option. In +CityxChange, the current ambition is to test this in Trondheim. In a pilot test in which participation is voluntary, the system may have to be implemented as a discount per kWh for building owners whenever they are able to keep their individual load below a pre-agreed level, which then can be temporarily raised through internal trading. Tasks 2.5, 5.6, and 5.10 will work out the details and probe the feasibility of this ambition, which will also depend on agreement from building owners, the DNO/DSO for Trondheim (Tensio, formerly TrønderEnergi Nett), and the regulator NVE. While Section 4.3 outlines general principles, we expect that substantial adaptation and revision will take place in these Tasks.

5.3.2.3. Potential for flexibility purchases by an institution

For flexibility purchases by institutions we identify two basic options. One model is that the DSO becomes a buyer of flexibility through reservation pricing, activation pricing, or both (Sections 4.3.3 and 4.3.4, system services). Another is that a third party local market operator (LMO) does essentially the same, but based on simplified criteria such as keeping the total load below a given level. In the latter case, the main goal would be to reliably slow the growth in load peaks and to incentivize long-term investments in flexible equipment. Our current ambition is to test flexibility purchases by an institution in the +CityxChange pilot areas in Trondheim.

5.3.2.4. Need for Community Grid Systems

The need to implement Community Grid Systems in Norway currently seems less pronounced than in Ireland, as surpluses of solar energy are not expected to be as problematic in the near future. However, this may change in the future. Regarding the +CityxChange test in Trondheim, we expect it may be counterproductive to implement a disturbance neutrality criterion of never having a positive net position (which will be applied in Limerick), in the test areas. The main reason is that this condition could entail unnecessary limits on energy output, which may counteract the +CityxChange objective of demonstrating PEBs.

5.3.2.5. Potential for LEM mechanisms in Norway

In the pilot test in Trondheim we think it could be useful to implement LEM mechanisms like those described in Sections 4.3.1.1 and 4.3.1.2, for testing purposes, although we suspect that the effect on behaviour may be relatively small. As mentioned earlier, these mechanisms could help to counteract the incentive for exploitation in the implementation of flexibility trading with activation pricing (Section 4.3.5) and may therefore be advisable to combine with this.

Furthermore, our current ambition is also to test the mechanism addressing the willingness to pay extra for local, renewable energy (Section 4.3.1.1) in the Trondheim test areas. In practice, this implies that the market platform to be developed in Task 2.5 needs to include a setting where customers can state how much they are willing to pay extra for local energy (beyond the price of Guarantees of Origin). Given the particular characteristics of the Norwegian electric power system, it may turn out that the willingness to pay for this is very low. However, it may be interesting in a European context.

5.3.2.6. Access to flexibility requests for balancing from LFM participants in Norway

The LFM's assets could theoretically be used for participation in system balancing markets through aggregators, such as the intraday- and TSO balancing markets. The most natural approach to couple the LFM with these markets may be that aggregators serving these markets could access the LFM’s flexibility through the LFM platform, with the DSO in a coordinating role. The feasibility of this issue could be explored in Tasks 2.5 and 5.10.

5.4. Implications for other European cities

The previous sections have described examples of how the method outlined in Chapter 4 can be used in practice. The method and the two examples of Trondheim and Limerick can be looked to by other European cities that seek guidelines for how to implement LFMs or similar forms of flexibility market platforms.

The two examples show that the suggestions for LFM design can diverge somewhat based on different conditions. For other European locations that aim to implement LFM solutions, it is advisable to apply the method in Chapter 4 but also to consider whether the conditions in Trondheim or in Limerick best match their circumstances. While our knowledge at this stage is somewhat limited, it seems plausible that Trondheim and Norway generally have the most atypical conditions compared with most European cities and countries. At the same time, however, certain market features that will be tested in Trondheim but not in Limerick could still be interesting to follow closely.

Aside from local conditions, another parameter is how ambitious cities are willing to be with tested solutions. While none of the options described in Chapter 4 are “simple”, some go into more unfamiliar territory than others. Cities that wish to start with something more familiar may want to look in particular at the model with an institution (e.g. a DSO) as a buyer of flexibility services (Sections 4.3.3 and 4.3.4). This is a “top-down” approach where the implementation lies largely with the DSO itself and may be more easily superimposed on the existing structure system than internal trading (Sections 4.3.1 and 4.3.2). Also, by using only reservation pricing (Section 4.3.3), some of the potentially more complex issues with activation pricing can be avoided. However, cities may also aim to implement internal trading in the LFM (Sections 4.3.1 and 4.3.2). This may require more novel software, more involved parties, and more special dispensations from regulators and DSOs. However, the stakes are generally lower for internal trading solutions than for system services.

It is beyond the scope of this report to provide an analysis for the +CityxChange Fellow Cities (FCs) with the same level of detail as for Limerick and Trondheim. Nevertheless, it is useful to summarise here, for the FCs’ corresponding countries, some of the key characteristics that are likely to matter when considering LFM design. This is presented in the table below. A more detailed mapping of the FCs will be a natural part of +CityxChange WP6.

Category	Spain	Czech Republic	Romania	Bulgaria	Estonia
Renewables share of gross elec. generation 2016 (EEA/Eurostat, 2018) (calculated from source)	38%	11%	41%	16%	11%
Number of DSOs (Küfeoglu, Pollitt & Anaya, 2018)	340	290	48	7	37
Passenger EV («all-electric») market share first half 2019 (Kane, 2019)	0.8%	0.3%	0.6%	0.8%	0.3%

Table 5.3. Characteristics of the countries of the Fellow Cities.

6 Conclusions

This report describes a "design tool" for the LFMs encompassing the Positive Energy Blocks in +CityxChange. This tool is a framework of guidelines for how to design a LFM depending on local conditions. The two +CityxChange lighthouse cities of Limerick and Trondheim are used as examples. The recommendations for the two cities are largely overlapping but also diverge in important ways. The points below summarise the main findings of this report.

- Local flexibility markets (LFMs) can be valuable tools in the future energy system, especially for preventing congestion in the low-voltage electrical grid.
- LFMs are envisaged mainly as add-ons to the existing electric power market, without changing how each participant has a retailer and a grid connection through a DNO.
- By enabling more intermittent, renewable energy to be installed, LFMs can support the +CityxChange goal of Positive Energy Blocks (PEBs) and Districts (PEDs).
- LFMs can incorporate both trading between LFM participants and institutions like Distribution System Operators (DSOs), Local Market Operators (LMOs) or aggregators, and internal trading (between participants).
- LFMs may possibly also incorporate and facilitate flexibility trading with external markets, e.g. system-wide balancing.
- Price setting for flexibility trading can be based on reservation payments, activation payments, or both. Including activation pricing is theoretically better, but can be more complicated to implement. It also carries a risk that LFM participants may exploit the system, especially by shifting consumption or production in the wrong direction in order to be activated and thus receive compensation. This has to be counteracted by particular measures, some principles of which are discussed in this report. Future +CityxChange Tasks, especially 2.3., 2.5, 4.10, and 5.10, should however explore this further.
- The Limerick solution for the +CityxChange pilot reflects conditions and priorities in Ireland's energy system, where it is currently difficult to connect more small-scale generation (like solar PV) in the LV grid. The LFM will be implemented within a disturbance neutral Community Grid System. In the +CityxChange test, a requirement of disturbance neutrality is that the Community Grid's collective total net position (production minus consumption) always is zero or less. This will allow them to connect more generation assets. This requirement of zero net production at all times implies that mechanisms are needed to absorb surplus production. The ambition is to do this both through a market mechanism for internal flexibility trading that incentivises load shifting, and by a grid stabiliser unit. It is not envisaged that the DSO will be a buyer of flexibility in the tested Community Grid System in Limerick.
- The Community Grid System solution may be attractive in countries and cities where a future with many prosumers per DSO is expected, and/or when the DSO role as a system operator is not far developed. The Community Grid System concept will be developed in detail in +CityxChange Task 2.3, and the implementation in Limerick will belong to Work Package 4.

- The pilot test envisaged for Trondheim mainly reflects conditions in Norway, but also aims to test elements that may be more useful elsewhere. The solution intends to test both internal flexibility- and energy trading, as well as the possibility for institutions like the DSO to buy flexibility in the LFM. It is not envisaged that the Trondheim pilot test will implement a Community Grid System committed to a non-positive net position. The main reason is that limiting output could counteract the +CityxChange goal of demonstrating PEBs. The software infrastructure will be developed in Task 2.5, and implementation in Trondheim belongs to Work Package 5.
- The market models outlined in this report will to varying degrees require regulatory dispensations. The feasibility of this for Limerick and Trondheim will be explored in Tasks 4.4 and 5.4, respectively. See also +CityxChange (2019).
- The results and guidelines of this report will be used to implement and parameterise LFMs for the cities in the project, leading to outcomes later described in D4.14: Energy profile of Community Grid and EV users, D5.6: Trondheim Flexibility Market Deployment Report, due in M36, and related reports on PEB implementation.

7 References

Ahlers, D., Driscoll, P., Wibe, H. & Wyckmans, A (2019). Co-Creation of Positive Energy Blocks. *IOP Conf. Ser.: Earth Environ. Sci.* (352), 012060, 1-7.

Backe, S., Kara, G., & Tomasgard, A. (2020). Analysis of Dynamic Capacity-based Grid Tariffs for Coordinated Demand Response in Neighbourhoods. *In Review.*

Bhatia, S. C. (2014 December 12th). Tide, wave and ocean energy. In *Advanced Renewable Energy Systems* (13). Retrieved from https://doi.org/10.1016/B978-1-78242-269-3.50013-9

CEDEC, EDSO for Smart Grids, Eurelectric & GEODE (2018). Flexibility in the Energy Transition. A Toolbox for Electricity DSOs [PDF-file]. Retrieved from https://www.geode-eu.org/uploads/GEODE%20Publications/2018/Flexibility%20in%20the%20energy%20transition%20-%20A%20tool%20for%20electricity%20DSOs%20-%202018.pdf

+CityxChange (2018a). Grant Agreement, ANNEX 1 (part A). *+CityxChange EU H2020, Grant Agreement 824260*, 2018.

+CityxChange (2018b). Description of Action. *+CityxChange EU H2020, Grant Agreement 824260*, 2018.

+CityxChange (2019). *D2.1 Report on Enabling Regulatory Mechanism to Trial Innovation in Cities* [PDF-file]. +CityxChange Deliverable. Retrieved from https://cityxchange.eu/wp-content/uploads/2019/08/D2.1-Report-on-Enabling-Regulatory-Mechanism-to-Trial-Innovation-in-Cities.pdf

Colle, S., Micallef, P., Legg, A., and Horstead, A. (2019). Where does change start if the future is already decided? [EY & Eurelectric Report]. Retrieved from https://www.eurelectric.org/media/3637/ey-report-future-of-dsos.pdf

ConEdison (2016). Brooklyn Queens Demand Management Demand Response Program Guidelines [PDF-file]. Retrieved from https://conedbqdmauctiondotcom.files.wordpress.com/2016/03/bqdm-dr-program-overview-6-28-161.pdf

CRU (2019). Electricity and Gas Retail Markets Report Q1 2019 [Information Paper, CRU19101]. Retrieved from https://www.cru.ie/wp-content/uploads/2019/08/CRU19101-Q1-2019-Retail-Markets-Report.pdf

Degefa, M. Z., Sæle, H., Petersen, I., & Ahcin, P. (2018). Data-driven Household Load Flexibility Modelling: Shiftable Atomic Load. *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Sarajevo*. Retrieved from https://ieeexplore.ieee.org/document/8571836/authors

EEA/Eurostat (2018). Gross electricity production by fuel. *Data visualization*. Retrieved on December 30, 2019 from https://www.eea.europa.eu/data-and-maps/daviz/gross-electricity-production-by-fuel-4#tab-googlechartid_chart_11_filters=%7B"rowFilters"%3A%7B%7D%3B"columnFilters"%3A%7B"pre_config_sector"%3A%5B"Coal%20and%20lignite"%3B"Natural%20and%20derived%20gas"%3B"Nuclear"%3B"Oil"%3B"Other%20fuels"%3B"Renewables"%5D%3B"pre_config_ugeo"%3A%5B"European%20Union%20(current%20composition)"%5D%7D%7D

EC Group (2015). Energiledd i distribusjonsnett. Behov for detaljeringsgrad i et 'nakent' energiledd [PDF-file]. Retrieved from https://ecgroup.no/media/energiledd-i-d-nett.pdf

Energi Norge (2018a). Drift og utvikling av kraftnettet – utforming av DSO-rollen. Nye og flere utfordringer – hvordan bør ansvar og plikter utvikles? [PDF-file]. Retrieved from https://www.energinorge.no/contentassets/2858551aafa94bb798d89a8edf15a42b/drift-og-utvilkling-av-kraftnettet---rapport-05-12-2018.pdf

Energi Norge (2018b April 17th). NVE revurderer nye effekttariffer etter stor motstand. Retrieved from https://www.energinorge.no/fagomrader/stromnett/nyheter/2018/nve-revurderer-nye-effekttariffer-etter-stor-motstanden/

European Parliament & Council of the European Union (2019). *Directive (EU) 2019/944 Common rules for the internal market for electricity and amending Directive 2012/27/EU*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944

Eurelectric (2014). Flexibility and Aggregation. Requirements for their interaction in the market [PDF-file]. Retrieved from https://www.usef.energy/app/uploads/2016/12/EURELECTRIC-Flexibility-and-Aggregation-jan-2014.pdf

European Commission (2016). Proposal for a Directive of the European Parliament and the Council on Common Rules for the Internal Market in Electricity. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016PC0864R%2801%29

European Commission/SETIS (2018). SET-Plan ACTION n°3.2 Implementation Plan: Europe to become a global role model in integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts. (June 2018). Retrieved from https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf.

Gerard, H., Puente, E. I. R., Six, D. (2018). Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework. *Utilities Policy*, 50, 40-48. Retrieved from https://www.sciencedirect.com/science/article/pii/S0957178717301285

Harbo, S.; Hansen, L.H.; Heussen, K. (2013). FLECH—Market Specification Analysis [PDF-file]. Retrieved from http://ipower-test2.droppages.com/Publications/FLECH%20Market%20Specification%20Ana lysis.pdf

Huseiernes Landsforbund (2018). Innspill fra Huseiernes Landsforbund om ny tariffstruktur [PDF-file]. Retrieved from https://www.huseierne.no/globalassets/horinger/2018/18.12.07---nve---innspill-effekttariffer.pdf

Kane, M (2019, Sept 28): European Countries Listed By BEV Car Market Share in H1 2019. Retrieved December 30, 2019 from https://insideevs.com/news/373465/europe-countries-bev-market-share-h1-2019/

Küfeoğlu, Sinan, Michael Pollitt & Karim Anaya (2018). Electric Power Distribution in the World: Today and Tomorrow [PDF-file]. *EPRG Working Paper 1826, Cambridge Working Paper in Economics 1846.* pp. 11. University of Cambridge. Retrieved from https://www.eprg.group.cam.ac.uk/wp-content/uploads/2018/08/1826-Text.pdf,

Minniti, S., Haque, N., Nguyen, P., Pemen, G. (2018). Local Markets for Flexibility Trading: Key Stages and Enablers. *Energies 2018*, 11(11), 3074. DOI:https://doi.org/10.3390/en11113074

NVE (2017). *Forslag til endring i forskrift om kontroll av nettvirksomhet. Utforming av uttakstariffer i distribusjonsnettet. Høringsdokument 5 (2017)* [PDF-file]. Oslo, NO: NVEs Hustrykkeri. Retrieved from http://publikasjoner.nve.no/hoeringsdokument/2017/hoeringsdokument2017_05.pdf

NVE (2019a). Høring av tiltak for utjevning av nettleie. Retrieved from https://www.nve.no/reguleringsmyndigheten/nytt-fra-rme/nyheter-reguleringsmyndigheten-for-energi/horing-av-tiltak-for-utjevning-av-nettleie/

NVE (2019b). Høring om ny nettleiestruktur til høsten. Retrieved December 18, 2019 from https://www.nve.no/reguleringsmyndigheten/nytt-fra-rme/nyheter-reguleringsmyndigheten-for-energi/horing-om-ny-nettleiestruktur-til-hosten/

Oslo Economics (2019). *Alternativer for utjevning av nettleie* [PDF-file]. Retrieved from https://www.energinorge.no/contentassets/2bbc59ec378a4917889e15a63020ba22/notat-om-alternativer-for-utjevning-av-nettleie.-15.09.19.-oslo-economics.pdf

Pérez-Arriaga, I. J., Knittel, C., Bharatkumar, A., Birk, M., Burger, S., Chavez, J.P., . . . Draffin, C. (2016). Utility of the Future: An MIT Energy Initiative response to an industry in transition. Cambridge, MA, USA: MIT Energy Initiative, Massachusetts Institute of Technology. Retrieved from https://energy.mit.edu/wp-content/uploads/2016/12/Utility-of-the-Future-Full-Report.pdf

Powersim (2017): Powersim Studio Expert. 64-bit version.

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Boston: Irwin/McGraw-Hill

Stewart, D. (2015). Submission to Commission for Energy Regulation by invitation issued in Consultation Paper CER16079 [PDF-file]. Retrieved from https://www.cru.ie/wp-content/uploads/2016/07/CER16079-Response-from-Micro-Electricity-Generation-Association-Of-Ireland-to-CER15284.pdf

THEMA. (2016). *Teoretisk tilnærming til en markedsløsning for lokal fleksibilitet* [PDF-file]. (THEMA Rapport 2015-37). Oslo: Thema Consulting Group. Retrieved from https://www.thema.no/wp-content/uploads/2016/04/TE-15-37-Teoretisk-tiln%C3%A6rming-til-en-markedsl%C3%B8sning-for-lokal-fleksibilitet-FINAL-1.pdf

THEMA & Multiconsult. (2018). *Descriptive study of Local Energy Communities* [PDF-file]. (THEMA Report 2018-20. Oslo: THEMA Consulting Group. Retrieved from https://www.thema.no/wp-content/uploads/2019/01/THEMA-Reort-2018-20-Local-Energy-Communities-Report-Final.pdf

USEF (2016). Work stream on aggregator implementation models. Recommended practices and key considerations for a regulatory framework and market design on explicit Demand Response [PDF-file]. Retrieved from https://www.usef.energy/app/uploads/2016/12/Recommended-practices-for-DR-market-design.pdf

USEF (2018). *Flexibility Platforms* [PDF-file]. White paper, version 1.0 final. Retrieved from https://www.usef.energy/app/uploads/2018/11/USEF-White-Paper-Flexibility-Platforms-version-1.0_Nov2018.pdf