*local **E**lectricity retail **M**arkets for **P**rosumer smart grid p**OWER** services*

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Abbreviations and Acronyms

Acronym	Description
AI	Artificial intelligence
ARMA	Autoregressive-moving-average
CACM	Capacity allocation and congestion management
CDA	Continuous double auction
DER	Distributed energy resources
DSO	Distribution system operator
ENTSO-E	European network of transmission system operators for electricity
ESS	Energy storage system
EV	Electrical vehicle
FLECH	Flexibility clearing house
HAS	Home automation systems
HFR	High-frequency
HFT	High-frequency trade
MIC	Minimum income condition
MAS	Multi-agent systems
MRS	Marginal rate of substitution
MU	Marginal utility
M1	Model 1
M2	Model 2
M3	Model 3
M4	Model 4
NETA	New electricity trading arrangement
OTC	Over-the-counter
PID	Proportional-integral-derivative
PV	Photovoltaic
RIL	Reinforcement learning
SARL	Stochastic approximation based reinforcement learning
TSO	Transmission system operator
TVA	Tennessee Valley Authority
WP	Work Package
ZI	Zero-intelligence

Executive summary

This document constitutes deliverable D6.2 in EMPOWER and is the product of task T6.2 in work package 6. It aims to explore the theories related to micro-markets and capitalize on former research related to market design and trading in a smart grid setting. The aim has been to define state-of-the-art and build a platform for specification of a detailed trading concept for local market design to be completed in task T6.3 in WP6.

The report has required investigation and comparison of theoretical trading concepts as well as practical solutions both within and beyond the energy domain, with the objective to describe the mechanisms of trade pertinent for the rest of the project. The work presented here has been developed partly in parallel with task T6.1 on initial market design and explores the theoretical and practical solution space for prosumer oriented trade in a local market as it was defined in D6.1. In addition, this report relates to D2.1 on business models and to D3.2 on the overall architecture of the technical system, which both provide important reference points for the specific local market design to be developed in EMPOWER.

The report presents in depth the key concepts in EMPOWER. These encompass the overall market design and its provisions (as discussed in D6.1), the contribution to indigenous supply by local prosumers and their interactions with consumers as part of a cooperative, and the use of trading agents. In particular, the key concepts chapter discusses the prosumers' role in the local market, their incentives and possible externalities, the potential that communities of commerce have, and the opportunities that social sites and shopping clubs provide.

Further, this deliverable provides a description of the basic trading process which is followed by a broad overview of the state-of-the-art of local energy trade and related concepts reported in the literature. Studies that represent issues of high relevance for developing the EMPOWER local market design are specified and synthesized and the various sides of trading mechanism and market design, as well as the variety of trading alternatives are being addressed.

Next, the report work dives deep into the theories of trade and markets to relate our survey of existing practices and pioneer academic work to well-established concepts in economics and game theory. From the discussions and meta-analysis mentioned so far, key characteristics of the trade concept that is to be further developed in task T6.3 are extracted. These are followed by a presentation of a selection of trade models that will serve as prototypes for the effort to be carried in T6.3. The report is finalized by a

discussion of the essential elements that will finally determine the EMPOWER trading concept to be hosted in the market cloud specified in D3.2.

The discussions and analysis presented in this deliverable D6.2 provide a sound theoretical and practical basis for the specific EMPOWER local market design to be developed. Centered around its key topic – prosumer oriented trade in a local market to improve integration of renewable energy and market efficiency – the report ensures that the necessary theoretical and practical tools for constructing the final trading concept in EMPOWER are all familiar. The subsequent task T6.3, where the local market modelling proposals are to be specified, will be carried with the help of, and the particular reference to, the knowledge on trading concepts and alternatives that has been extensively provided in this present work.

1 Task description

The primary objective of this work package 6 is to explore the theories on the micro-market and capitalize on former research related to market design and trading in a smart grid setting. The idea is to synthesize this and specify a concise market arena that can support trading at the user end of the supply chain in - full scale, real-time environment of prosumers and the surrounding supply system. This deliverable is a product of task T6.2 termed "Exploration of theoretical and practical solutions for prosumer oriented trade". The task has required investigation and comparison of theoretical trading concepts as well as practical solutions both within and beyond the energy domain. Task T6.2 has specifically carried out theoretical work on apt trading concepts for the local market defined in task T6.1 and presented in the deliverable D6.1. In addition to an analysis of existing theoretical and practical market solutions related to the project, this report should further describe the mechanisms of trade pertinent for the rest of the project. Output of task T6.2 and beneficiaries of D6.2 are primarily the tasks "T6.3 Trading concept development", "T6.4 Create basis for implementation", "T3.3 Design of the Interfaces of the Platform" and "T5.1 Specification and Design". To sum up, task T6.2 has addressed the following key research objectives:

- Explore the concept of micro-markets based on theories
- Investigate zero-intelligence trading concepts
- Explore and assess recent agent-trading concepts associated with micro-grids or general smart grid developments
- Investigate different forms of equilibrium models versus simple decentralized trading structures such as simple double auctions and bilateral trade
- Investigate popular business-based trading and auction platforms on the web

2 Introduction

2.1 A study of prosumer oriented trade in a local market

This document constitutes deliverable D6.2 in EMPOWER and is the product of task T6.2 in WP6. It represents and endeavours to answer the key research objectives listed in the task description above. The work described has been developed partly in parallel with task T6.1 on initial market design, task T2.1 on business models and task T3.2 on the overall architecture of the technical system that is going to support the marketplace concept and trade in EMPOWER. Multiple references will be made to deliverables stemming from these activities.

Familiarity with “D6.1 Market design” and “D2.1Timing Based Business Models” would significantly benefit the reader of this document. It is especially important to understand the different roles that can be assigned to the smart energy service provider (SESP), the combined service, flexibility and energy market and how the local market is situated between the well-established central marketplaces and the consumers/prosumers. The task that has now been concluded has explored the theoretical and practical solution space for prosumer oriented trade in a local market as it was defined for the EMPOWER project in D6.1. Task 6.2 has also provided input to ongoing work in WP8, which has targeted stakeholders.

2.2 What this document tries to achieve

This document tries to determine what supports trade in a local energy market populated with, above all, prosumers. The overall design of the market has been described in D6.1. The objective here is to investigate what criteria must be observed and what trade models could best fit the objectives of the market and the framework that has been laid out.

On a more general note this document represents a partial fulfilment of the ambitions set forth in the original proposal:

“Develop and verify a local marketplace and innovative business models including operational methods to encourage micro-generation and active participation of prosumers to exploit the flexibility that this creates for the benefit of all connected to the local grid.”

Hence, the trade specified should first and foremost focus on the local aspect, ways to encourage micro-generation and engagement of especially prosumers in the local marketplace. In the context of trade within a local market we must assume that the majority of participants are non-professional traders. To fairly engage these is thus a principal requirement.

How to integrate distributed renewable generation effectively as part of the general power system is a key question that must be answered.

Another key question often asked is how a local marketplace can co-exist with other micro-markets in addition to or instead of a well-managed centralized energy pool. D6.1 and partly D3.2 have tried to answer this. Here further implications for trade are discussed. An electric power system with infrastructural weaknesses and an unreliable supply may be greatly alleviated if incentives for local generation and local trade can take place close to the terminal points in the distribution system. In regions, where utilities have monopolized energy sale, local trade may emerge as a viable and competitive alternative. But even in the parts of Europe, where central markets have been fully liberalized, local markets could offer an alternative, not least in those regions where high volumes of intermittent energy must be managed and balanced. The inherent cellular concept defined by a local market or micro-market could, in an aggregated form, possibly challenge a centralized concept, too.

Energy prices defined in a central day-ahead market will inevitably create a crucial value reference for co-existing local markets that also have unconstrained access to energy traded. The local advantage can be found in the added value offered by the community and in the demand for increased flexibility to manage intermittent resources and increased occurrences of high, concentrated loads in part of the infrastructure. It is not apparent that central control will be able to manage this effectively without significant local contribution. Moreover, keeping a marketplace for energy and ancillary services separated and sharing the increasing cost of real-time balancing through general taxation seems intuitively less efficient than what a local market can offer. However, this requires that the local marketplace treats energy and flexibility as the two sides of the same coin and offers a form of simultaneous trade. Increased trade frequency is likely to play a central role in relation to this and represents an important aspect of the content presented here.

Exploitation of flexibility is essential. In D6.1 we proposed a way to integrate a combined energy and flexibility market with related services. D2.1 defined the main business rationale for this. Services can be divided into two groups. 1. Those, which can be traded in real time, i.e., diagnosing and repair. 2. Those, which represent a standing offer from a platform-based business concept. The first group of services can be traded in real-time as an asset strongly connected to energy and flexibility. The other group represents a way to recruit, engage and retain participants. But it may also be used to facilitate increased trade in general. A prerequisite for this is again the community concept that was introduced in D6.1. References to shopping clubs, both on- and off-line, come close here. To establish the principles for trade within such a community is another objective of this report.

To sum up, the local market is primarily meant to encourage and better exploit local renewable generation and alleviate the power system, primarily in the low voltage area. In turn this could repurpose the central energy system and market and help to meet political climate goals. The current power system and the principles governing current trade in the liberalized market treat externalities in ways that can question common welfare principles and fair distribution of cost and income. One example is how the cost required to balance intermittent energy traded today is distributed. We will apply regular welfare principles to our trade concept, but will in the first place not attempt optimization of welfare. However, we believe that the integrated market concept holds a potential, which could in time offer improved welfare overall.

2.3 What this document does not try to answer

This report will not provide the final design specification of the EMPOWER trade concept. It will only establish the principal provisions for this. The design specification will be produced in task T6.3 which is still ongoing. The key question on how to integrate distributed renewable generation is an issue that demands broader attention than the purpose of task 6.2 requires. European transmission system operators (TSOs) like the SwissGrid battle this problem every day (Janssen and Kunze 2015). The findings in this report could possibly inspire solutions to the problem on a wider scale. Yet, this is beyond the scope reported here.

Description of stakeholders that could be active in the market is treated in WP8. Participant roles will only be highlighted here in conjunction with specific trading subjects.

Task 6.2 has not attempted to systematically evaluate different trading models up against each other by means of simulations. Comparative analyses based on meta-research and some lesser analytic exercises have therefore been applied. It is important to understand that the EMPOWER project, and in particular WP6, explore a novel solution space established by modern ICT and smart grid technologies. The aim is to conceptualize and establish a proof of concept, not necessarily optimize. This requires an explorative and iterative effort. The current report represents an intermediate result at this stage in the project, not a conclusive manifestation. As research in the area which EMPOWER ventures is currently picking up momentum new findings of immediate relevance could and should be picked up later and incorporated, thus staking an adjusted course for the ongoing tasks T6.3 and T6.4.

2.4 Method of approach

Our primary approach has been to study pertinent literature and simple meta-research. Emphasis has been placed on state-of-the-art literature, which specifically addresses energy trade by means of agents in a local market. Comparative studies of different approaches to trading in a local environment have been made. This has been complemented with examination of a few pertinent trade models that do not address the idea of local markets in particular, but offer insight that would help in forming a hybrid market for energy, services and flexibility. Although some market and trade concepts address this issue, they all treat the above aspects as separate entities that are managed in sequence and in different markets. An empirical study has been conducted to highlight the inherent potential that prosumers can offer in local trade.

The market design proposed for EMPOWER in D6.1 distinguishes itself from established energy markets in other ways, too. Agent based trading, community focus and technology enabled operations are the most important. All three are key building blocks in the proposed EMPOWER concept. We have therefore specifically addressed literature that can create a basis for further work related to the exploitation of these elements.

Pioneer work related to multi-agent systems (MAS) for local energy trade has been given specific attention. To back this up we have also looked to the financial world where agent based trading or algorithmic trading can boast a 20 year legacy. MAS provide in many ways a closed environment for common trade. Issues related to information sharing and biases may not offer the same opportunities or challenges which are prevalent in less technically oriented markets. Amateurs stand a better chance of taking part without being directly engaged on a continuous basis. This must be related to the type of automation that allows high-frequency trade (HFT) and cross-trade which we know have revolutionized security trading. Old truths related to continuous and non-continuous trade may prove obsolete. Sequential markets may be a thing of the past and efficiency issues may come close to trivial as information sharing and processing capabilities can operate at magnitudes unreachable by manual approaches.

Significant effort has been made to extract and synthesize experiences reported by others on the topic of community oriented commerce. We reference practical approaches to commercial systems that involve both cooperation and self-interest.

Based on such studies we have dived into theory to determine what effect the novel aspects introduced could have on basic principles of trade and markets.

Finally, we have made a selection among investigated models reported that we think come closest to what we want to achieve in EMPOWER. We have not synthesized this into one alternative. This is not the ambition. It is more to extract the intrinsic features of these models and use them as a basis for design of the final trading concept in task T6.3

2.5 How to read this report

We have structured the rest of the report in accordance with the introduction above. First, we deliberate on the pivotal aspects of EMPOWER specifically introduced in D6.1. These include aspects related to the general trading process itself, prosumers, commercial communities and cooperatives and trade agents. The discussion provided complements and slightly reiterates on trading aspects introduced in D6.1. More importantly, besides highlighting issues associated with vital for EMPOWER concepts, it relates to theory that is presented later. Then, this report offers an overview of historic efforts that have conceived concepts pertinent to local energy trade and the related exchange of services. Different features that characterize these issues have been elicitated.

Close familiarity with previous work in EMPOWER such as D6.1 on the overall market design and which is referred to several places is essential. D2.1 on business models provides a basis for understanding the incentives that can be established around the market design. As suggested above, the reader should first acquaint himself/herself with key aspects that represent the most novel aspects of EMPOWER, in addition to the hybrid market that was described in detail in D6.1. This happens in Chapter 3. Within this chapter the section on commerce communities and trade provides a kind of template for the type of communities that the EMPOWER project has defined. We then discuss different agent concepts and the potential that they offer to EMPOWER. From there, in Chapter 5, we provide a broad overview of the state-of-the-art of local energy trade and related concepts reported in the literature. Next, in Chapters 6 and 7, we explore the theories of trade and markets to relate our survey of existing practices and pioneer academic work to well established concepts in economics and game theory. Key characteristics of the trade concept that we will further develop in task T6.3 are extracted before we, in Chapter 9, discuss a selection of trade models that will serve as prototypes for this effort. We close with Chapter 10 by discussing the essential elements that will finally define the EMPOWER trading concept to be hosted in the market cloud specified in D3.2.

3 Key concepts in EMPOWER

3.1 Introduction

In addition to the overall market design and its provisions that were discussed in "D6.1 Market Design" three other key concepts represent the frontier of research related to local markets:

1. The contribution to indigenous supply by local prosumers.
2. The organization of prosumers and consumers in a community where members cooperate is essential.
3. The use of trading agents.

For the purpose of trade and market liquidity we pose questions related to departmentalization of the market and the trade process. These questions are answered as part of the literature study that is conducted later.

Next, the role that local prosumers can play is discussed. Here, results from an analytic exercise using empirical data from one of the pilot sites targeted for EMPOWER has been used. This investigation helps to understand potential incentives for trade and the impact of externalities. The dependency on legislation that counters or supports local trade is essential to understand.

Previously, we have pointed out the growth of energy cooperatives across Europe which has been the subject of recent reports, such as the one authored by Roberts et al. (2014). In task T6.2 we have further addressed this in terms of trade and commerce. This has been elaborated on in the Section 3.4 "Communities of commerce" where insight is shared on, among other issues, how shopping clubs work. Typical intrinsic characteristics such as self-interest blended with coalition thinking and prosumer oriented activities are emphasized. The instrumental role of affordable and easily accessible services and products (such as an "app" discussed in D6.1 and D2.1) for commercial engagement is addressed. The use of reward mechanisms and the importance of membership fees and rebates to trade are also highlighted. The importance of this is further discussed in the theoretical part that follows later.

We also introduce a description of various trading agents applied in commercial and financial activities today. Their importance in the financial and security markets cannot be underestimated and since other pioneering work on local markets have applied such software agents it is important to understand also the basic concept and what agent based trade can do to markets.

3.2 Overview of market design

This chapter briefly recaptures the EMPOWER market concept described in D6.1 ("Market design"). D6.1 presents a unique market concept that is flexible and adaptable to different judicial and regulatory regimes. More specifically, it is a local market built up of three brokerage/sale elements: energy, flexibility and other services. The market is founded on a local community and different types of prosumers, consumers, producers and storage facilities are included. A new business role - the SESP – is to have the most central functionalities with respect to local market operation. The SESP is expected to serve as a legal entity, provide a consolidated and integrated ICT platform and ensure efficient trade of energy and energy related services. Moreover the SESP will organize and facilitate the energy oriented actions of the neighbourhood community. In addition, the SESP should be carrying the above described responsibilities within the three varieties of local market structures: the local energy market, the local flexibility market and the local service market.

In D6.1 the local market is described according to different market settings.

- The market operates in an islanding mode.

In this case, it should to be ensured that the necessary technology is available to achieve the internal balance.

- The SESP carries the trade within the local market, but also trades in the central market.
- The SESP offers a general trading floor but interactions with the wholesale market are left to other market agents (aggregators/retailers).

In D6.1 an illustration of the EMPOWER market concept has been designed based on the structure of the Nordic power system. Novel aspects of this concept include the market agents' relationships with the SESP and most importantly the implications that these relationships have for commercial activities.

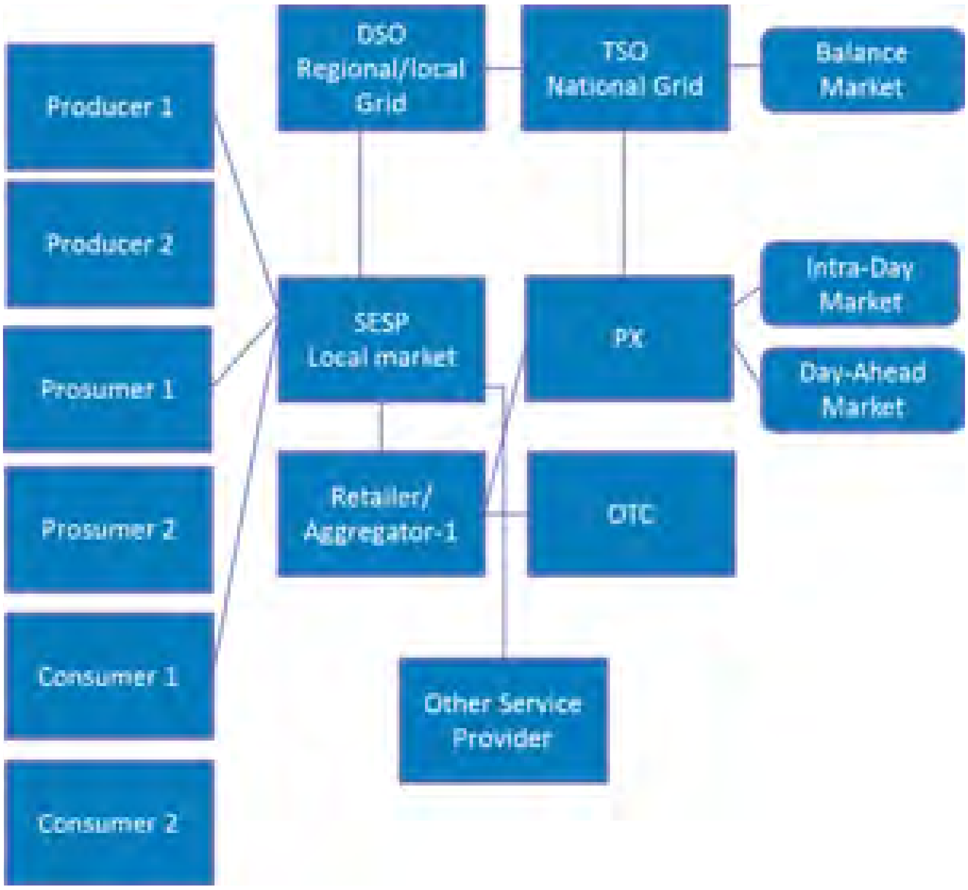

Figure 1: The local market and the SESP's possible relationships to other market players with reference to the Nordic power system (Source: EMPOWER Deliverable D6.1)

Currently, no decision has been made regarding how the local market should be divided, if in any way at all. Departmentalization has been a common way to facilitate different forms of trade in liberalized wholesale markets. However, practices vary considerably. A couple of examples reproduced from Schubert et al. (2002) are shown in Figures 2 and 3.

Figure 2: The NORD POOL model

Figure 3: The England and Wales model

The NORD POOL model encompasses a financial derivatives market for futures, forward and option contracts, a day-ahead energy market (Elspot) and an hour-ahead spot market (Elbas), both for physical contracts. A real-time regulation market is designated to the respective TSOs in the Nordic power system to ensure balance between generation and load at any time, and to provide a price for participants' power imbalances.

The essential idea of this departmentalization is to assure the necessary volumes early and to hedge risk. The markets early in the sequence allow traders to assure desired volumes as much as possible. The latter stages are meant to compensate for inaccuracies in forecasting, planning and actual operation. With its split the NORD POOL model also diversifies the type of energy products that can be traded and thereby invites more stakeholders into the marketplace. In the case of England and Wales departmentalization is much simpler, but based on a similar logic reflected in the NORD POOL model.

A fundamental question to be asked in the case of EMPOWER is whether trade needs to be split up in different markets as it has been exemplified here. If so, could a combination of a derivative market and a real-time balancing market suffice? If traders are willing to pay for stability and take less risk, trading in futures and compensating for instabilities in the flexibility market this should be possible. The option should be especially viable in places with relatively small trading volumes and marginal deviations from the expected/forecasted. However, someone must absorb the risk and the question will be at what price.

A popular saying is that the best real-time regulation market is the spot market itself. If forecasts and plans reflected the future accurately there would be no need for real-time compensation. Can informed agents in a local market operate with sufficiently accurate prognoses in the day-ahead market to avoid compensating measures in real-time? In that case how will congestion be managed? Could a continuous market that allows inelastic matches or even retrieval and replacement of unmatched bids and asks at very high intervals eliminate risks and reduce the need for derivatives and a separate real-time balancing market? These are pertinent questions to be asked. We have sought the answers in the literature.

3.3 Prosumers, incentives and externalities

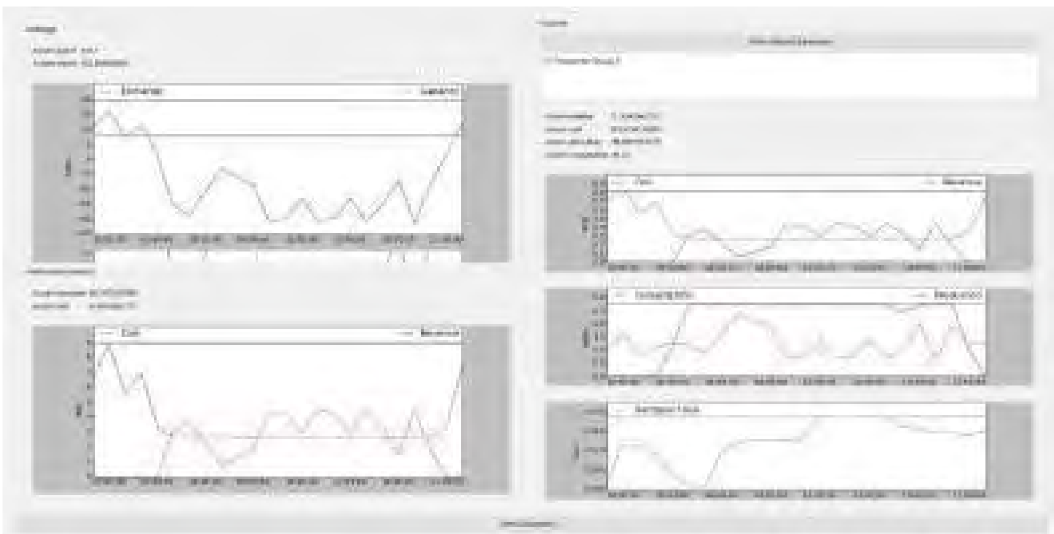

Figure 4: Tool created to analyse empirical data from Hvaler

This effort has been based on an empirical analysis supported by a tool that was created for the purpose, and which will be further used in task T6.3 (Figure 4). The empirical basis has been gathered from the Hvaler area in Norway, which has been nominated as one of the pilot sites in WP7. The tool offers a way to analyse consumption and production patterns in neighbourhoods with different numbers of consumers, regular suppliers and prosumers. Different restrictions can be customized and introduced. This enables a way to understand how trade can take place and what incentives could help to drive it. For task T6.2 only generation from roof top PV panels has been taken into account. This has been done to keep things simple. Another reason is the fact that currently all local generation at Hvaler comes from privately owned solar panels. In order to determine incentives and potential impact of prosumers in the neighbourhood the contribution from 10 prosumers under different price regimes, regulations and local recipients have been studied.

3.3.1 Selling or storing surplus energy

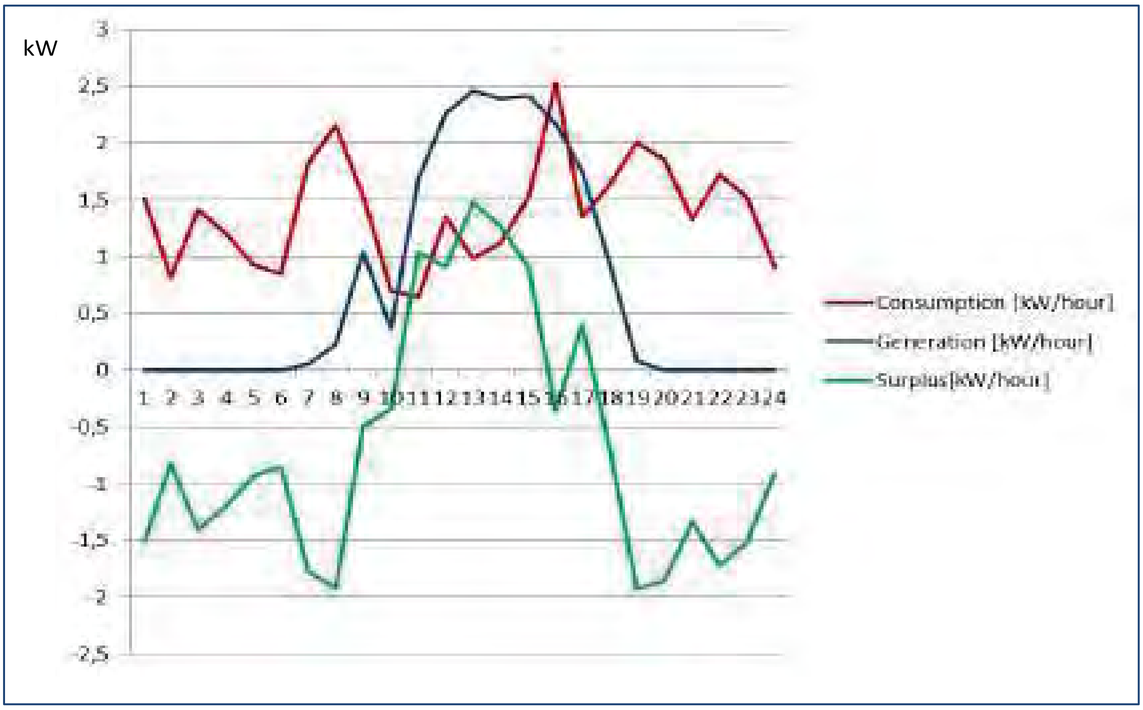

Figure 5: Generation profile for a PV generating facility in September 2015 (blue line). The red line shows the consumption profile for the household the same day. The green line shows the net surplus. In a more temperate area the surplus generated would be higher due to lower consumption.

Figure 5 shows the generation profile of a single prosumer on a sunny day in September 2015 from a 3,1 kW panel. A similar profile on a slightly clouded day is shown in Figure

6. The conditions would be quite similar on a sunny day in April. A less clear day with light clouds is going to break up the generation profile.

Despite lower sun angle in the northern part of Europe roof top panels are still relevant for many households in Scandinavia.

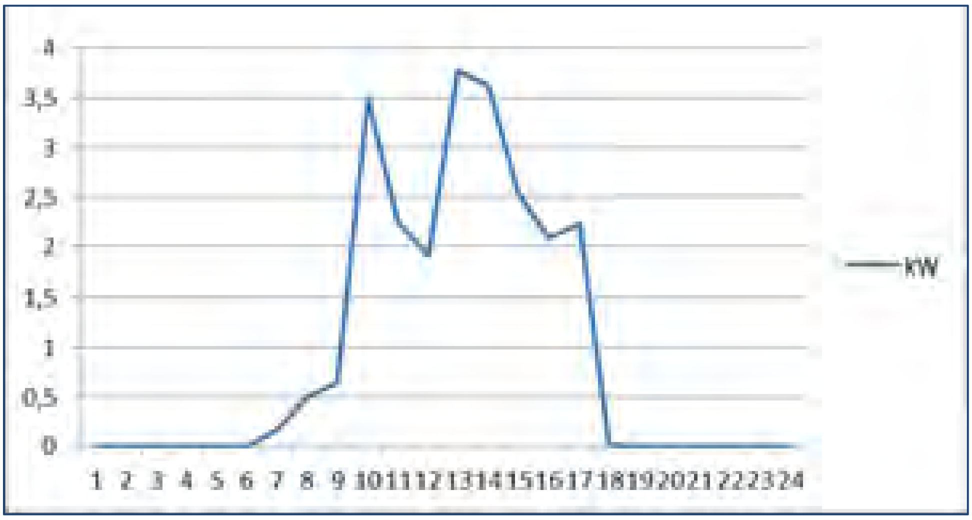

Figure 6: A lightly clouded day yields more irregular generation. Results from a 5 kWp panel

Interest is picking up as prices of panels fall. This is also the case at Hvaler. During late November, December and January generation is very low, while rapidly picking up in February as high pressure periods with a lot of sun dominate and with water and snow amplifying radiation. Still, generation follows the sugar top profile which characterizes all roof top based energy generation. What differentiates the Nordic prosumer from many others is the relative high consumption throughout the day and especially beyond June and July. This reduces the surplus available for storage or sale. In the more temperate areas of Europe the surplus generated would generally be much higher and extend across more hours. However, that difference is reduced when the residence remains vacant for a period. The profile shown in Figure 7 represents a vacant household and could also well illustrate the magnitude of surplus generated further south with the same type of equipment.

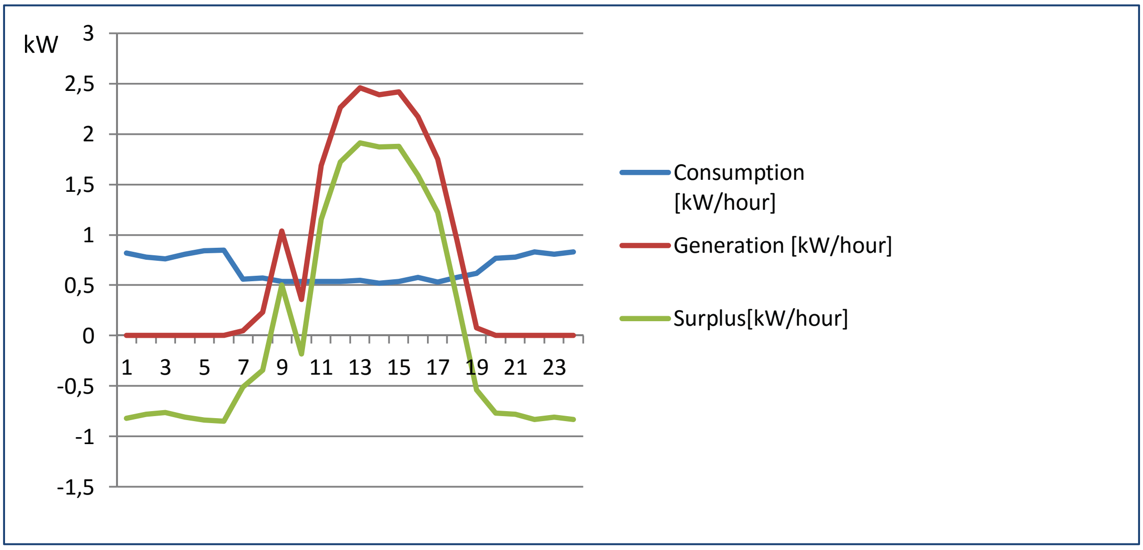

Figure 7: The surplus generated for a household vacant during a weekend

Table 1: Load reduction for neighbouring consumers during peak hours

	load reduction kWh/h					
	Surplus	**2**	**4**	**6**	**8**	**10**
24.aug	25	13	6	4	3	3
25.aug	0	0	0	0	0	0
26.aug	17	9	4	3	2	2
27.aug	20	10	5	3	3	2
28.aug	59	30	15	10	7	6
29.aug	57	29	14	10	7	6
30.aug	63	32	16	11	8	6
31.aug	45	23	11	8	6	5
01.sep	4	2	1	1	1	0
02.sep	33	17	8	6	4	3
03.sep	58	29	15	10	7	6
04.sep	54	27	14	9	7	5
05.sep	14	7	4	2	2	1
06.sep	61	31	15	10	8	6

Table 1 shows how the surplus could be applied to reduce loads of neighbouring consumers during peak hours. Each column refers to a load reduction, either a single peak or a load lasting multiple hours. Each row corresponds to a date with a surplus recorded. Each column represents the number of consumers being able to purchase local energy from the prosumers that day to reduce the load on the central system during peak hours. Example: On September 4th 27 consumers would be able to purchase local energy to alleviate the central distribution system with 2kWh or 2 x 1kWh/h, or 14 could choose this form of exchange to achieve 4kWh or 4 x 1kWh/h. This example ignores the fact that trade also needs to take into consideration generation. On a cloudy day the change in generation might vary from minute to minute. This intermittency requires special considerations as it can be hard to fulfil obligations, for instance, in a day-ahead market. Balancing issues in the neighbourhood for such reasons will also be a concern.

The fact that solar energy is only available for a fraction of a 24-hour day suggests that net accumulated surplus over a day is negative for a household with the type of consumption that has been displayed here. The only exceptions are when the household stays vacant or during mid-summer when little need of light and heating creates a consumption profile that comes close to the one shown in Figure 7.

Unless the prosumer increases the size of his roof top facility or installs other means of generation (i.e. thermal heating by means of bio mass) he/she will have to import energy from other local or central sources. Looking at solar power alone this also defines the greatest difference in terms of trade between a Nordic and a continental household equipped with the same PV-panel. However, a significant surplus is generated during the middle of the day. Figures 5 and 7 both show that sales or storage potential exists between 10 o'clock in the morning and 6 o'clock in the evening. How to manage this well is a paramount issue in EMPOWER. It can be shown that 5-6 days with consistent high pressure conditions and mostly clear skies could accumulate a full day's energy buffer for the household presented here[1].

Self-balancing is not possible within a community with the type and level of generation presented here. However, a neighbourhood populated with a number of roof top panels of 3,1 kW at peak hours could be used to balance consumption and generation during peak hours in the morning and during the evening. Analysis shows that during the period Aug 24 through Sep 6 2015 10 of the prosumers at Hvaler could supply local consumers during peak hours directly or through local energy repositories. This is shown in Table 1. On a good day 10 prosumers may support 10 to 15 consumers in the neighbourhood with a 2kWh or 3kWh during morning and evening peaks when prices typically are higher and loads in the distribution grid are usually high. However, it requires that local exchanges, in contrast to general feed-in, are encouraged somehow. This depends on government regulations and the distribution system operator's (DSO) operational policy. Certainly, local supply could alleviate the better part of the distribution net. Sole focus on

[1] 33 kWh consumption against 6 kWh surplus a day.

the individual, rather than a community, may erode the possibility of a self-balancing neighbourhood for a part of or the full day.

3.3.2 Policies and grid tariffs

The prosumer is confronted with four basic choices: invest in a storage system and store energy locally (i.e. thermal, mechanical, electro-chemical storage), rent storage space beyond the premises of the house or sell the energy straight away locally or to the central market.

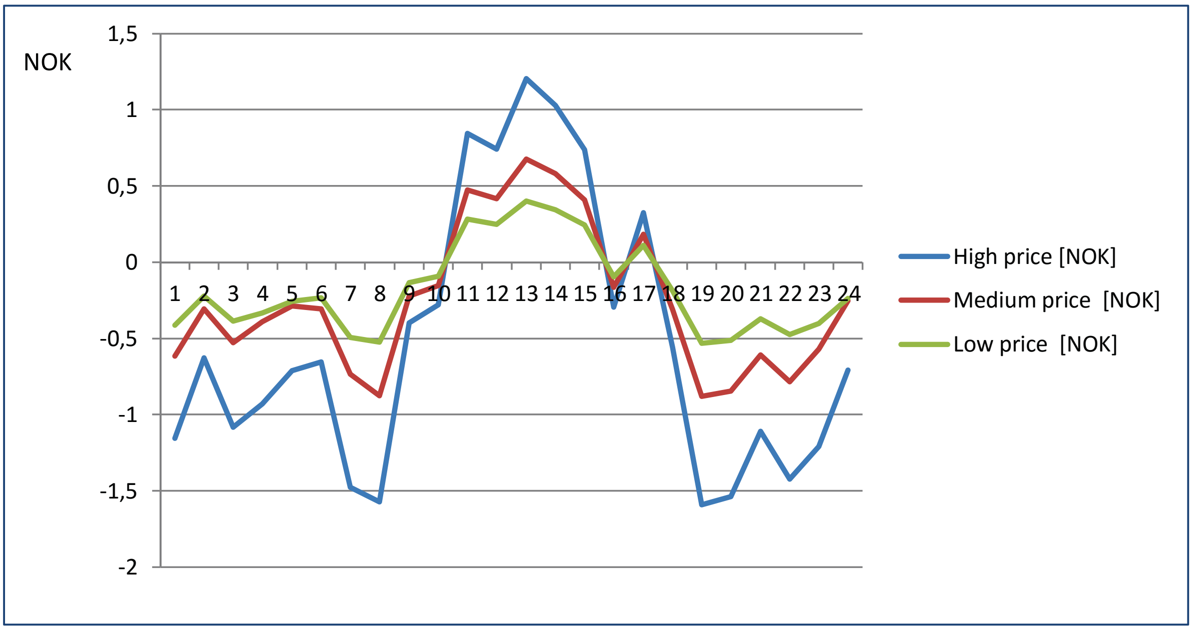

Figure 8: The cost and income situation for the household in Figure 5 under different price regimes. Y-axis shows cost in NOK

Figure 8 shows the prosumer's situation under different price regimes, assuming that generated energy is primarily used for self-consumption. The "Low price" scenario represents the actual situation for the prosumer. The "Medium price" scenario represents a high price situation in Norway while the "High price" profile shows the household's cost-income share using prices for the northern part of Germany. If energy prices remain fairly stable the incentives for storing energy for future use will decrease. Price change, however, offers an arbitrage possibility. The storage options are thus more attractive. In the instance of sale the question whether to sell the surplus in the central market or to one of the neighbours arises. Commissions, green certificate policies, grid tariffs and penalties imposed if sales obligations are not met – all these externalities will influence this decision.

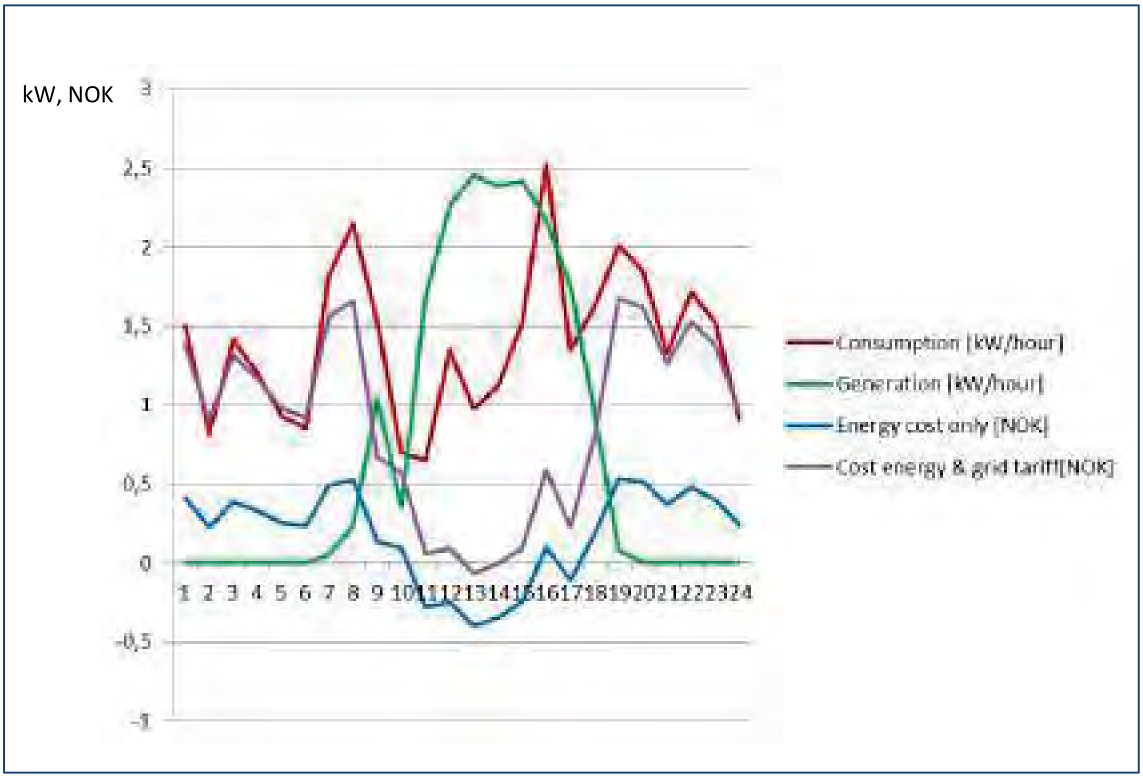

Figure 9: The effect of grid tariffs on the cost-income profile of the prosumer

Figure 9 shows the effect of a common grid tariff per year in the form:

Tariff = F + K * energy

Where F is a fixed annual fee and K is a unit fee per kWh. All taxes are included.

More specifically, the tariff for the Hvaler pilot area is expressed:

Tariff [NOK] = 2142 + 0,4175 * energy, where energy is measured in kWh

It shows a situation where there is no feed-in tariff from the prosumer. However, imports are charged with the regular tariff. This tariff is designed to encourage self-consumption and not export. Besides, it penalizes local trade. Even when a self-balancing neighbourhood is possible and the central grid is exempt from the load otherwise imposed a tariff like this will discourage local trade. Until recently German legislation has honoured exchange of energy within a "territorial relation" to the facility. A commonly accepted definition of "territorial relation" has not been produced. However, consumers that are locally energised by smaller energy plants have, according to this rule, a good chance to receive exemption from the energy tax which in early 2015 was 2,05 €cent/kWh. This constitutes a significant incentive for local trade.

With the advent of AMS some utilities have started to introduce power tariffs similar to the ones offered to industry and agriculture. They are typically in the form:

Tariff = F + K * energy + g(power), where g(power)

is a function that reflects hourly peak consumption in some way. One example is

Tariff [NOK] = 625 + 0,2562 * energy + 35 * $\frac{12}{N}\sum_N max^*\ energy_n$, where

max^* is the average of the three highest hourly peaks during a month. With a change to this type of tariff the trade focus will alter considerably. The focus would be to eliminate the highest peaks during a month. This is illustrated in Figure 10 where self-consumption of generated energy is used to kill an hourly peak which potentially could produce a significant cost increase (but leaving another peak of lesser magnitude).

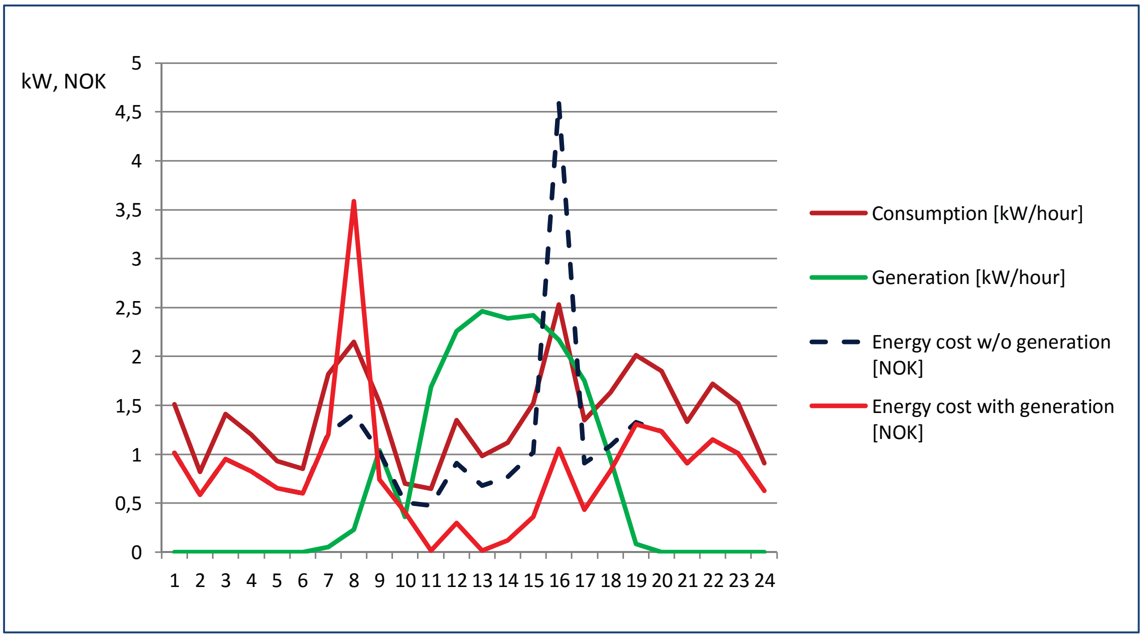

Figure 10: The same consumption and generation profile as in Figure 9, but with a peak power tariff producing a different cost profile

Externalities of this kind can be very important and change the focus of trade through a change in government policies. Using energy prices as a basis for establishing optimal equilibrium may not be optimal. A pure energy tariff like the one shown first can be easily incorporated. However, a peak load tariff like the one described here produces more complex assessments, but also amplified trade incentives. We will discuss this in the theory part later.

It seems to be a valid claim that the DSO and authorities would be better off to treat an organized neighborhood of consumers and prosumers as a whole, charge according to the import and export loads on the shared connection point and leave the community to manage its common assets for the benefit of all stakeholders involved.

3.4 Communities of commerce

3.4.1 Introduction

An essential part of the EMPOWER market concept is the idea of a community that harbours the local market. At the centre of this is situated the SESP. The rationale behind this has largely been described in the EMPOWER deliverable D6.1 and illustrated in Figure 1. The business foundations have further been explored in D2.1. To address a neighbourhood as a community with shared interests is not a novel idea. The idea that a community provides some basic principles and provisions for internal trade should furthermore be apparent to everyone who is a frequent user of social media, such as Facebook and LinkedIN, as well as online games on the web. However, to use the membership of a community as an important asset in trade, and in local energy trade specifically, makes a difference. Nothing in the literature on local markets that we have reviewed addresses this aspect. Our basic claim in EMPOWER is that a community offers an added value to members. This added value creates a basis for increased trade, increased attractiveness of the marketplace compared to more traditional alternatives and helps to reduce risks. In recent years, the rise of prosumer communities and renewable energy facilities with citizen ownership has been significant. In Germany alone, more than 1000 initiatives had been recorded at some time in 2014. In Holland about 500 have been reported (van der Schoor and Scholtens 2015). Our study in task T6.2 gave useful insight into what criteria are emphasized by the members of the cooperatives regardless of what business model they have chosen. Not surprisingly, there exists strong similarities to the energy cooperatives that emerged in the USA as part of Roosevelt's New Deal in the 30s. Moreover, the criteria that seem to create the added value are largely the same as those that cooperatives in other domains build their enterprise on. What is more surprising is why today's players in existing markets have overlooked much of this. Take away some retailers' effort to create concepts with loyalty points we see little evidence of citizens embracing these added values in their own business development. To highlight these values and to create a backdrop for the final discussion on the models for local trading that we have analysed certain key characteristics will be discussed in the next paragraphs.

3.4.2 The perceived value provided by cooperatives

The energy business world-wide has witnessed community oriented initiatives seeking to establish a secure supply of electric energy for the past 80-90 years, especially in rural areas.

Figure 11: The web page of a long established energy cooperative in the US

In recent years, the citizen initiative to take over and buy the electricity grid in Berlin is but one example. Focus on co-ownership that brings influence and profit sharing, focus on more rapid change and conversion towards renewable energy source are among the arguments used by this extensive initiative. “The Energy Cooperative” located in Tennessee represents a traditional cooperative approach (Figure 11). Arguments like “together we are stronger” and “we know what is needed for us” are arguments that go way back.

The US Tennessee Valley Authority (TVA) Act, passed by the federal US government in 1933, authorized the TVA Board to construct transmission lines to serve “farms and small villages that are not otherwise supplied with electricity at reasonable rates”. This created a surge in consumer cooperatives that was later copied other places in the world. One of the oldest still around is the Dunn Energy Cooperative founded in 1939.

The community initiatives for consumers have been revitalized as prosumers have made their entry into the energy business, much on the same grounds. Warren and McFadyen (2010) investigated and compared opinions and sentiments related to wind parks in Scotland. Their basic question was whether community ownership affects public attitudes to wind energy. Their conclusion was quite decisive that it does, in a positive way. Results show that ownership consistently tended to yield more frequent positive responses to wind power in general, and local wind farms specifically. Ownership may not necessarily transform a negative attitude to a positive one. But it may amplify the positive parts and suppress the negative ones. Embedded here lies the added value.

Van der Schoor and Scholtens (2015) studied thirteen local community initiatives of varied maturity in the Netherlands in the period 2010-2013. One key observation made was that local community energy initiatives, in contrast to municipality or commercial entities, clearly prioritize community benefits.

This relates to cooperative traditions that span two centuries. Institutionalized cooperatives typically conduct their affairs according the Rochdale Principles defined way back in 1844. The bearing beam here is that there must be a voluntary and transparent membership open to all. Consequently people must have a reason for joining. They perceive a potential value for themselves. Key motivation for seeking membership can then be closely related to what value a new member is looking for.

- Financial/economic benefits – Some cooperatives are able to provide members with financial/economic benefits.
- Quality of life – Serving the community through a cooperative because doing service makes one's own life better is perhaps the most significant motivation for volunteering. Included here would be the benefits people get from being with other people, staying active, and above all, having a sense of the value of ourselves in society that may not be as clear in other areas of life.
- Socialization - Being part of a group with a common goal.
- Giving back – Many people have in some way benefited from the work of a cooperative and volunteer to give back.
- Altruism – Some volunteer for the benefit of others.
- A sense of responsibility – Some see participation in a community as a responsibility that comes with citizenship. In this case, they may not describe themselves as volunteers.
- Career experience – Volunteering offers experiences that can add to career prospects.

All of these elements, if closely coupled with the energy exchange in both promotional efforts and in practical day-to-day trade, provide a perceived added value that is likely to be interpreted as a discount or bonus, depending on whether it is associated with purchase or sale (Figure 12).

What is less common with the cooperative concept related to the EMPOWER community introduced in D6.1 is the inclusion of both suppliers and buyers, of amateurs and professionals. The fact that the community does provide a shared benefit for all should make the players more inclined to hedge around common goals and place less emphasis on short term self-interest. We hypothesize that this lessens the aggressiveness of the trade and will help to reduce the spread and increase liquidity. In a later paragraph we will explain why.

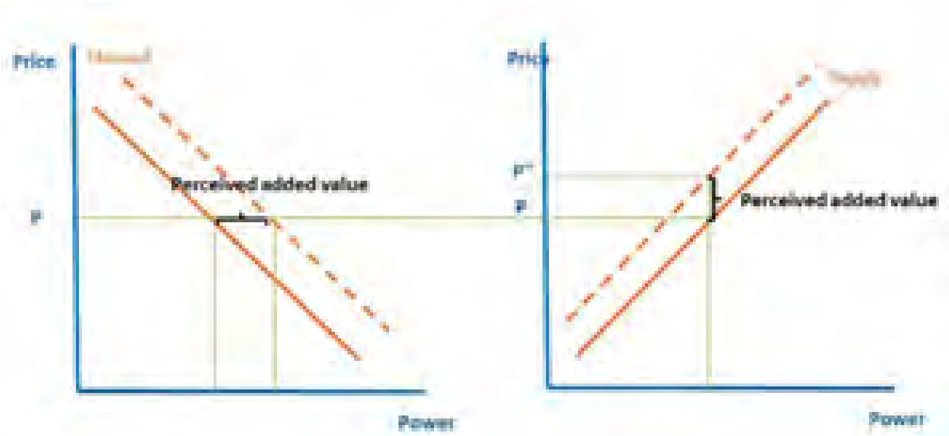

Figure 12: How perceived value can change demand and supply. Buyers may experience a notion of subsidy or discount. Sellers might see it as a volume raiser and as a desirable price mark-up

3.5 Social sites and shopping clubs

Social media has created an attractive marketplace for vendors of all kinds. Although trade is not directly part of the social site, it offers plenty of entries to such. Advertisements and promotional notes are currently saturating Facebook, YouTube and other sites. The virtual trading booths are but a click away. The volume of goods being traded in this way is still soaring. Common to all is that people and commercial vendors all are members. For people there exists no entry fee. However, the personal data required or volunteered is a very strong currency that vendors crave and which the host of the social site benefits from.

Shopping clubs represent a different form of commercial community. Private and semi-private shopping clubs are not new. They have existed off-line for more than a century. Private shopping clubs can usually only be joined by invitation and goods cannot be made available otherwise, at least not with the discounts that club memberships assures. True private shopping clubs source their products directly from the manufacturers. They usually don't buy liquidation stock from retailers. Membership comes with an initial fee or with an obligation to purchase or sell a certain volume per year. Shopping clubs may include auctions, competitions, classified markets for selling and buying. The bearing beam for membership retainment is a reward and reputation mechanism based on how much you buy or can offer customers. A high level of engagement measured in purchase or sales volume is rewarded with certain privileges such as higher discounts, priorities in trade and increased exposure for sellers. In Table 2 we have listed a selection of popular shopping clubs online.

Table 2: A selection of shopping clubs

Name	Membership requirements	Membership benefits
The Shopping Club (UK)		▪ Save with Reloadable Retail Cards – Up to 10% Cashback ▪ Discounted Retail Vouchers – Up to 10% Discount ▪ Save with online discounts – Up to 50% Discount ▪ Save with cashback – Up to 50% Cashback ▪ Save even more with cashback plus – Up to 10% discount and 25% Cashback ▪ Save when shopping by phone – Up to 50% Discount ▪ The Shopping Club membership card – Up to 50% off at 4,500 local retailers ▪ Print & Save Vouchers – Up to 50% Discount ▪ Save on limited time offers ▪ Lotto ▪ Competitions ▪ Purchase service for anniversaries etc. ▪ Classified online market for buying and selling items
KupiVIP.ru (Russia)	One open part and one VIP part that requires certain commitments	▪ VIP Silver o Access to exclusive shares sale tagged with VIP Silver o 15% discount on all cosmetics o VIP Silver requires a purchase volume of 5000 rubles ▪ VIP Gold o Access to private shares SALE tagged with VIP Gold o Early access to new shares sale at 30 min. earlier than usual o 20% discount on all cosmetics o VIP Gold requires a purchase volume of 10000 rubles ▪ VIP Platinum o Access to private shares sale tagged with VIP Platinum

		○ 30% discount on all cosmetics ○ Early access to new shares sale at 1 hour earlier than usual ○ VIP Platinum requires a purchase volume of 100.000 rubles
Shoppingklubbar.se (Sweden)	Membership fee of 25 SEK per year.	Syndicates multiple shopping clubs in Sweden. Campadre with 500.000+ members is the biggest. ▪ 40-60% discounts compared to regular shopping ▪ Members initiate several campaigns for well-known brands to rally increased trade for such brands. ▪ Sellers are loyal to pledges made to buyers and delivers promptly ▪ Rebate vouchers and codes can be earned
Clubshopping.br (Brazil)	None	▪ Unmatched variety in merchandise traded ▪ The customer will have the opportunity to earn and accumulate bonus points to win off purchases on the site ▪ Freight discounts
Club Shop		▪ Cashback on purchases ▪ Discounts ▪ Fund raising ▪ Loyalty benefits ▪ Shopper Member: A Shopper Member shop at a store listed in the ClubShop Rewards Mall and she/he will earn a percentage of the purchase as an automatic rebate, paid in "ClubCash". ▪ Affiliate member: In addition to Shopper Member benefits, an Affiliate Member is also entitled to earn Referral Commissions on purchases made from a ClubShop Rewards Mall store from the people the member referred to become Shopper Members. An Affiliate will have access to Transactions and Sales Reports and a Training Guide to learn how to refer people to become Shopper Members ▪ Partner: A partner will have his/her own business and be able to refer people to a partner's own ClubShop Rewards Mall. A partner will have access to the exclusive TNT Marketing Plan to build a global sales and membership organization. A GPS (Global Partner System) to provide directions, training, tools, sales management reports and support for your business will also be at a Partner's disposal.

As can be observed from **Error! Reference source not found.**Table 2 the shopping clubs listed create a citizen community around pure commerce. They turn customers into prosumers who initiate and run trade campaigns to recruit more members, generate higher sales volumes and promote certain brands. Suppliers obtain intimate contact with customer segments and can drive sales volume up together with other members. A cooperative trade model lies at the heart of this despite the fact that the recruitment basis has an entirely self-interest driven focus. Reward and loyalty points, together with discounts, create strong incentives for participation and help to increase market liquidity. Large discounts can be achieved simply because price mark-ups are lower as there are no intermediate link between manufacturer and customer.

3.5.1 Self-interest versus coalitions

Local energy communities, such as the Dutch ones described by van der Schoor and Scholtens (2015), are established on a shared vision and common goals, but may otherwise be rather informal. According to these authors, local community energy initiatives distinguish themselves from similar local enterprises in that they clearly prioritize community benefits. They state that *"In many respects, decentralized renewable and sustainable energy production appears to be a means to the end of improving social coherence"*. Even in the most informal case coalitions are formed to better achieve community objectives. It may be argued that this is a prerequisite for an organization with few formal structures. The firm criteria that underpin shopping clubs suggest that commercial communities may exist even if the notion of strong social coherence is missing. Circumstance and personal incentives define coalitions, for instance in temporary sales campaigns, despite strong emphasis on self-interest by the individual participants. The EMPOWER concept will attempt to blend these aspects. The tension between self-interest and coalitions will surely colour market rules and trading strategies. The theory for this is expanded in a later paragraph.

3.5.2 Membership fee and the SESP as a market maker

As for many shopping clubs a membership fee will be introduced for EMPOWER community members. The membership fee may also take the form of a part ownership. Membership could also have different levels similar to the ones that Club Shop and KupiVIP.ru offer and operate with differentiated fees. There are several reasons why a fee is beneficial. The membership fee is a token of commitment and can be measured. Commitment is a prerequisite, albeit not sufficient alone, for active engagement. As pointed out in D6.1, the SESP needs to facilitate the trading. As such the SESP should also be required to operate as a market maker. For this purpose capital is needed. The membership fee will provide the SESP with the means to play the role of a market maker to lubricate the trade. In a small community this might be particularly important. It might also be demanded in transient periods when either generation or consumption is low. An energy storage that is controlled by the SESP can be helpful for this. As a market maker the SESP can stimulate local trade by providing purchase and sales incentives for the community members and thereby avoid spill-overs to other markets. The SESP may choose to do this by reducing the spread and to buy and sell energy volumes to facilitate balancing efforts. Similarly to shopping clubs the community management and the SESP may decide to use the membership fee to offer bonuses for the top performers. The membership fee may not be the only capital source. As pointed out in D6.1, the SESP may also use part of the revenue from the subscription achieved with the DSO to generate funds that allow it to operate as a market maker. As for shopping clubs discounts on products and services as well as cash-backs are likely to be sufficient to justify a membership fee. This is where the “other services” part of the EMPOWER concept will play an important role.

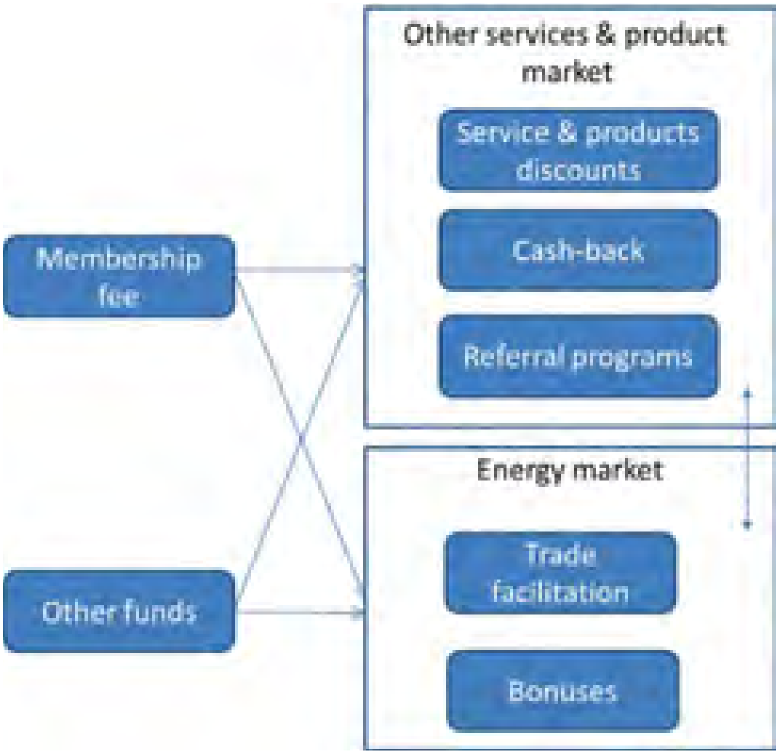

Figure 13: An illustration of how the membership fee enables a strong connection between the service market and the energy market

Like a shopping club recommending hardware, such as energy displays, HAS systems, as well as apps, smart phone apps, insurance offers and maintenance help, niche specific products and services can be purchased for a discount. Community members can be rallied for campaigns and customer data may alone be the preferred compensation for the rebates that suppliers are asked to give. Figure 13 illustrates how part of the service market in EMPOWER could help to facilitate the local energy market and support market making. The membership fee provides the SESP a reserve, in addition to earned funds, to operate as a market maker. For the individual member the membership and the paid fee earn him or her direct access to services and products offered with significant discounts. Depending on the membership level it may also yield preferences in trade or priorities in competitive situations. Part of the reserves established can be applied to support referral programs which in turn should yield more market participants and more trading activity. Trade in this part of the service market could be supported by auctions similar to those found at eBay[2] or eBid[3] or by means of fixed price interactions similar to those maintained by Amazon.com.

3.5.3 Online auction sites for services and products

Figure 14: The 10 most important online auction sites in the world according to TopTenReviews

Multiple online auction sites have adopted several of the basic criteria for participation in a shopping club and fully cover the trading process described earlier. TopTenReviews[4] is a site that monitors online commerce activity. Figure 14 shows the ranking of the most important auction sites with eBay ranking on top. All operate according similar principles.

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[2] See the Live Auction Department of www.ebay.com.

[3] See www.ebid.net

[4] http://www.toptenreviews.com/

However, 10TopReviews evaluations show that they differ significantly according to selling fees, selling features, listing options, payment options and support options. The details of these are shown in Figure 15. The most important to note in this context are the different selling fees and listing options. Observe the use of fixed fees, commissions, listing fees and upgrade fees that yield profits for the site. Note also “Automatic Bidding”, “Buy Now Button” and “Resolution Center”. The two former include a form of automated bidding or a simple form of sales or buyer agent. Automatic bidding allows the buyer to set a maximum limit to what he or she is willing to pay and leave the rest to the agent. The “Buy Now Button” allows the sell to set a fixed price of the item that is offered. This allows the buyer to purchase the item without having to participate in an auction. The “Resolution Center” provides clearing and conflict resolution support whenever a problem arises between a seller and a buyer. The principles associated with these specific options are going to be treated in subsequent paragraphs.

Figure 15: TopTenReviews’ criteria for comparing and ranking different online auction sites

3.6 Agents and trade

3.6.1 Introduction

Trade in EMPOWER will be conducted by software agents that represent community members. They could cover all the steps of the trading process. More and more agents are equipped with a knowledge base that can be updated at each trading cycle. Forecasting and trade policy development constitute the prime focus for this. However, intelligence may not be a prerequisite neither for use nor for market performance.

Efficient interactions between agents will be pivotal for all that is going to take place. As pointed out in D6.1 agents are required to reduce the burden on community members. Agents may monitor the marketplace continuously and can significantly alleviate non-professional traders like ordinary house owners by screening out the more complicated parts of the market. Moreover, all agents controlled by the technical platform supported by the community may be offered the same information. This should cater for proper market efficiency. Similarly, this will reduce the chance of biases, undesired gaming and speculations. A potentially counter-intuitive aspect should be noted. The complexity of agent behaviour is primarily a reflection of the intricacy of the environment and not necessarily due to the characteristics of the agent itself. A proper trading concept and market design is therefore essential to create a robust and desired behaviour at both individual and aggregated level. This is supported by the seminal work of Gode and Sunder (1993). It is also one of the reasons why zero-intelligence agents are so important. They provide a means for determining the soundness of the rules of trade and the market design in general. But their simplicity makes them especially apt for the type of traders that a community involving non-professional traders represent. Focus on robustness, security and a satisfactory long-term trading strategy may be more important that an aggressive, profit or utility oriented approach. Having stated this, the EMPOWER community will involve several agents that operate basically in the best interest of their owner. This implies the use of MAS (Multi-agent systems). The introduction of a MAS will inevitably bring about issues that pertain to game theory, and how both individual and community interests should be best catered for. This is a topic of a later paragraph. Some work, that has pioneered local markets, has also applied MAS techniques (Vytelingum et al. 2010, Kahrobaee et al. 2014 and 2013, Ilic et al. 2012). These are also discussed later. Here we will address some basic aspects of ZI agents, MAS and algorithmic trading. Since the mid-nineties algorithmic trading has revolutionized the financial market. Algorithmic trading comes in different guises. Some systems are provided as a MAS platform that can serve multiple players. Others represent a single number-crunching entity with a very high capacity meant to serve only one trader. A particular form of algorithmic trading is of special interest to EMPOWER. This is high frequency (HFR) trading. In the following subsections we will discuss ZI agents, MAS and HFR-algorithmic trading

3.6.2 Zero-intelligence (ZI) agents

The simple forms of automation that online traders at eBay, AW and eBid offer may be thought of as very simple agents. They have no memory. The trading strategies are usually very simple. The more advanced are called sniping agents[5]. They typically place a bid on behalf of a user seconds before an auction closes. Some are specific for one site only. Others can be set up by means of third party support to take part in auctions at different sites.

A buyer's agent will typically be given a maximum bid limit and be instructed to increase a bid with a fixed increment every time a competing bid beats the present in a classic English auction. This creates a very characteristic trading pattern. One of the first to study this type of online trade was Ockenfels and Roth (2002). Not surprisingly, the trade may not provide an optimal outcome for the agent owner. This very much depends on the rules governing the marketplace. The greatest benefit rests with the possibility to let the agent replace the owner for the most part of the trading process. Despite the deficiencies of such bidding agents it should be noted that all the online auction sites referenced earlier apply these simple agents and have done so since their inception. They are unquestionably popular with many traders. This must be embraced by EMPOWER.

Gode and Sunder (1993) investigated the performance of ZI traders in double auctions. This has constituted a basis for several, more recent studies using MAS trades (Vytelingum et al. 2010, Kahrobaee et al. 2014 and 2013, Ilic et al. 2012). Gode and Sunder (1993) built their study on the work of Smith (1962) which presented evidence that "*Walrasian tâtonnement*[6] *conducted by a central auctioneer, is not necessary for market outcomes to closely approximate economic equilibrium, even with a handful of traders."* Furthermore, Smith implied that equilibrium predictions of economic theory can

[5] One example is http://auctionsniper.com/

[6] From Wikipedia: A type of simultaneous auction where each agent calculates its demand for the good at every possible price and submits this to an auctioneer. The price is then set so that the total demand across all agents equals the total amount of the good. Thus, a Walrasian auction perfectly matches the supply and the demand.

accurately describe many trading mechanisms, not just Walrasian tâtonnement, in a variety of environments. The performance of ZI machine traders were compared to profit –motivated human traders. Each ZI trader generated random bids or asks distributed independently, identically, and uniformly over the entire feasible range of trading prices that were allowed. Gode and Sunder (1993) found that the ZI agents were able to attain economic surplus like the human traders. The discipline of the double auction, and not the presence of rationality, and profit motivated behaviour were sufficient to extract the desired surplus. This suggests that utility-maximizing agents are not imperative to derive market equilibria and desired welfare. Applied to local markets Ampatzis et al. (2014) found that ZI agents behaved logically in this context too, following the rules of supply and demand.

However, in Gode and Sunders' study (1993) ZI agents displayed no signs of profit dispersion change over time. While aggregate efficiency was found to be indifferent to any degree of profit motivation and learning, reduced profit dispersion across individuals was not. ZI can therefore, to a great extent, generate aggregate rationality for a neighbourhood market, such as the one contemplated in EMPOWER, even though individual economic rationality is imperfect or even absent.

In contrast, individual performance hinges on more intelligence. However, with the community harvesting the benefit of satisfactory surplus and increased economic welfare aggressive individual profit seeking may be sacrificed for simplicity of agent design. As pointed out the benefit of the community will drizzle over its members in the longer term still.

A particular form of ZI agents based on control engineering has been proposed by Carella (2014). Carella's proposition is that elementary control engineering will suffice to make an agent able to establish the correct price for a piece of goods, provided that a sales target is specified. In contrast to ZI agents basing their bids and asks on a mere probability distribution, such agents will try to achieve a user specified objective. They have no knowledge of the market, but may be tuned to maximize profits or turnover by responding to signals that are picked up during a trading process. Carella's proposition can easily be translated into a continuous bid and ask situation where a trading agent is able to implicitly build a price strategy by offering a small volume for sale in the beginning to test the response in the market. Carella argues that PID (proportional-integral-derivative) controllers will suffice. This is a three component controller which can be expressed mathematically according to the expression:

$$\mathbf{U_{t+1}} = k_p * e_t + k_i \int e_\tau d\tau + k_d * de_t/dt$$

where kp, ki and kd are called the proportional, integral and derivative factors respectively. They modulate their respective correctional component to compensate for the measured deviation, $\mathbf{e_t} = y_t - \hat{y}_t$. y_t is actual performance at time t. $\hat{y}_t$ is desired outcome at time t. $\mathbf{U_{t+1}}$ represents the desired action at time t+1. This can be expressed in terms of an ask process as follows:

$$\mathbf{A_{t+1}} = kp * e_t + ki \sum e_i + kd * (e_t - e_{t-1}) / \Delta t$$

Without knowing the demand curve in the market a trading agent can rapidly adjust to a positive or negative response in the market. Assume that the agent wants to sell a fixed volume (V) and achieve the highest price.

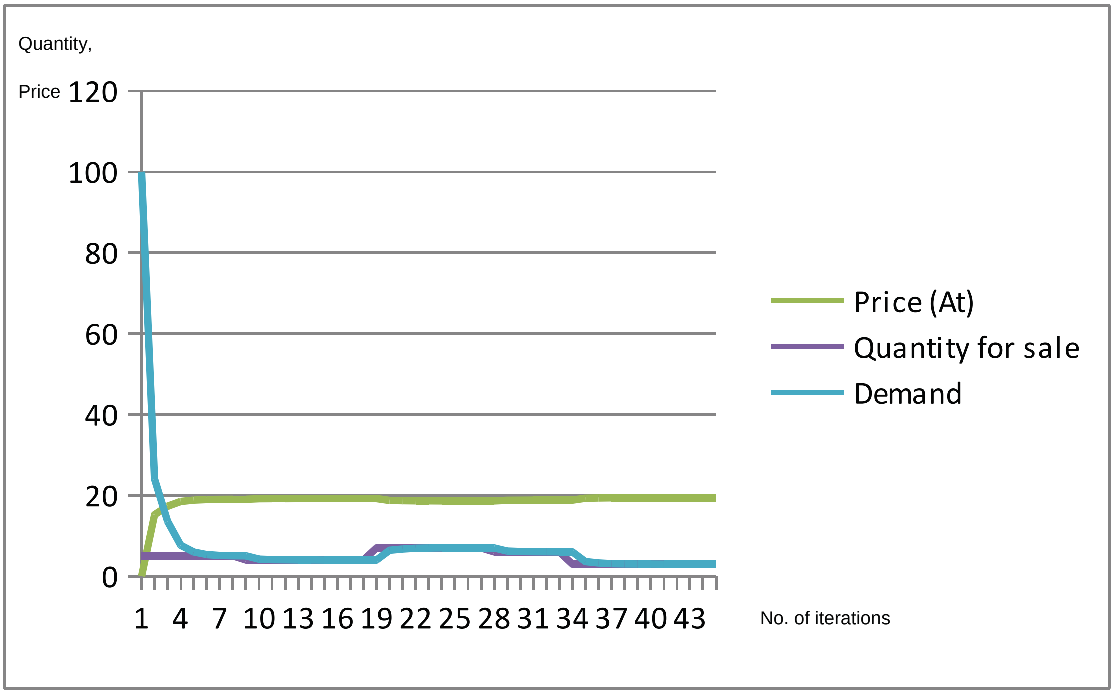


Figure 16: Ask process where a selling agent tests the demand with a small offer, V= 5, and rapidly finds equilibrium price in a continuous trading process.

It may test the market by asking a very high price or a very low price first. If the trading latency is prolonged the price asked may be too high. If the volume of bids posted is very high for a given price the agent will raise the price at the next occasion. If properly tuned the coefficients will be able to avoid serious offshoots and stabilize the ask process very rapidly. Figure 16 illustrates this phenomena with a traded volume of 5. Price equilibrium is rapidly established. Even when the ask policy is changed at t = 19 (volume asked made available is increased to 7 and down to 5 again) stability is rapidly achieved.

This can further be shown for two negotiating ZI agents based on a PID implementation operating under different user policies. Hence, it is possible to equip users with very simple means of trade and ensure that sales and purchase targets are met for each. At the same time we can assume that market efficiency and surplus can be attained. A PID agent is particularly well suited to manage flexibility needs in the market in real-time and to maintain balance between supply and demand. This is not unique for the EMPOWER case. This is a general problem and has recently been addressed by Janssen and Kunze (2015). European TSO's suffer significant cost for capacity procurement that is required in order to handle potential deviations between the renewable production forecast and the actual generation. The cost for this capacity reserve becomes socialized by adding it to the grid fees of all connected electricity consumers. A better solution would be to place the cost where the source of the problem lies. Janssen and Kunze (2015) also state that "*Many European markets are characterized by a separated, dis-aggregated market for tertiary balancing power, re-dispatch electricity as well as further comparable products. This leads to complicated markets with sub-optimal price structures."*. Consequently this is a practice that should be avoided, at least in a small cellular market like the one proposed in EMPOWER.

3.6.3 Multi-agent systems (MAS)

Multi-agent systems (MAS) approaches have already been applied for local markets (Ygge and Akkermans 1999, Vytelingum et al. 2010, Kahrobaee et al. 2014 and 2013, Ilic et al. 2012) and related smart-grid oriented applications (Dusparic et al. 2013). MAS contain a number of agents which interact through communication. They are able to act in an environment where they have different spheres of influence which may coincide. They can be linked through other organizational relationships. Agents simultaneously choose an action to perform and, as a result of the actions they select, an outcome. The actual outcome depends on the combination of actions. A good introduction to MAS can be found in Wooldridge (2002). Ygge and Akkermans (1999) pioneered MAS in relation to markets. When comparing MAS based approaches for different markets with centralized methods they found that MAS could in certain cases outperform the latter. They also stated that "*local data plus market communication yields global control*". This implies that for distributed resource allocation problems multi-agent equilibrium markets yield optimal solutions. In what way depends on the strategies adopted by the agents and the environment constituted by the market design. This will be discussed in more detail later. An interesting study by Vytelingum et al. (2010) compared the efficiency of market outcome for zero-intelligent agents versus knowledge-based agents with adaptive-aggressiveness strategy. In general, agents characterized by adaptive aggressiveness are proven to contribute for higher market efficiency. This does not contradict Gode and Sunder's (1993) earlier study, but stresses a point that should be adopted in EMPOWER. Namely the fact that it could be worthwhile to cultivate agents over time to learn new strategies. It does not contradict a strategy where it can be useful to start simple.

3.6.4 HFR-algorithmic trading

Algorithmic trading has become common place in the financial market. From a meager start in the mid-1990s algorithmic trading was thought to be responsible for as much as 73 percent of trading volume in the United States in 2009 (Hendershott 2011). There exist many different algorithms which are used by different types of market participants. The algorithms depart from ZI agents as they are designed with memory and are equipped with sophisticated statistical or machine learning methods. The algorithms range from *trade execution algorithms* that are designed to minimize price impacts when large volumes are bought or sold to *electronic market making* and *liquidity detection*. The former type simply reduces the total volume into small batches that are slowly released into the market. An electronic market maker profits from selling at the ask price and buying at the bid price, thus earning the bid-ask spread. Liquidity detectors sniff out whether a large order is ready to be released to a market and take action. Various forms of statistical arbitrage agents can also be found. They seek out price imbalances between normally strongly correlated securities. An emerging realization is that algorithmic trading has provided increased liquidity to the financial market and reduced the spread (Hendershott 2011). This can be especially attributed to a particular type of algorithmic trading typically referred to as high frequency trading (HFT). HFT algorithms are characterized as high-speed and sophisticated quantitative and algorithmic computer programs for generating, routing, and executing orders. The mere speed and frequency of the trade where the market situation can be sniffed out, orders split and price limits adjusted very rapidly reduce the spread, assures more rapid clearing and a higher aggregate set of transactions. Consequently, the magnitude of incremental price changes will also be reduced. Both algorithmic trading in general and HFT in particular offer significant potential in a local market which is subject to a high degree of change due to intermittent supply and higher individual impact.

4 The basic trading process

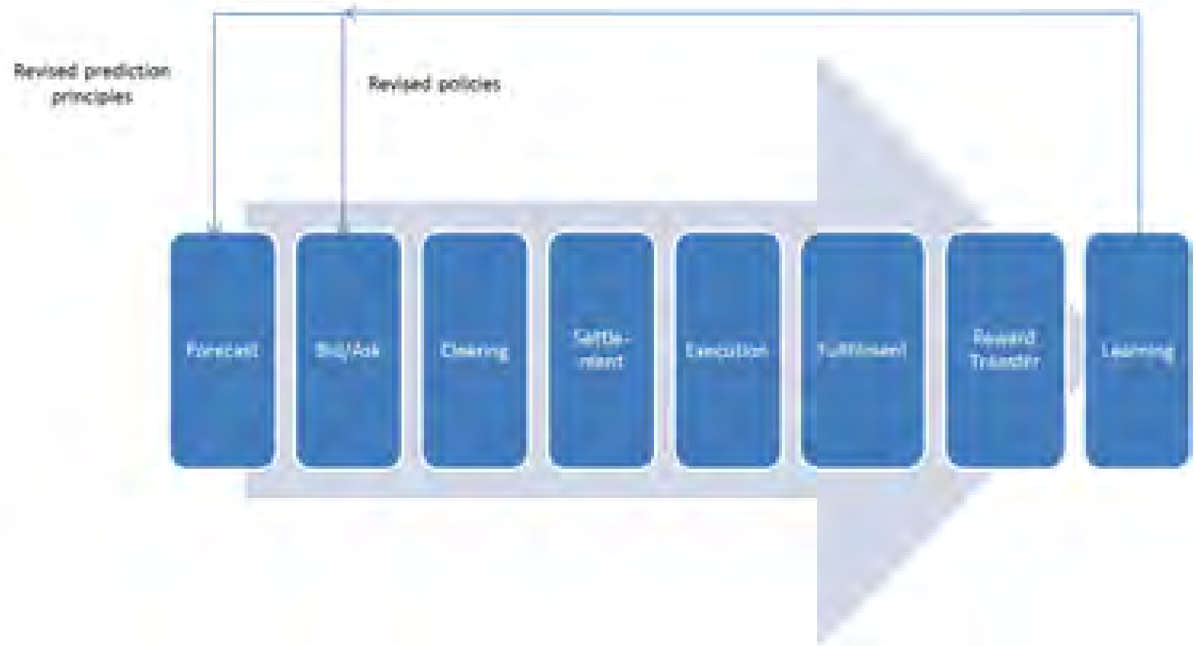


Figure 17: The basic trading process

The basic trading process for most goods is depicted in Figure 17. Although the content of each step in the trading process may vary the flow is mostly the same.

4.1 Feedback cycles

Associated with the flow presented above a cyclic element has been introduced in our depiction that represents feedback and learning.

All trade involve some kind of learning. Market participants tend to excel by analysing trade history, prices and strategies of the past in order to better determine future situations. In the financial domain many investors lean heavily on the concept of “technical analysis”. A technical analysis resides entirely on trade history to determine future signals for buying and selling. Two main types of feedback are usually associated with a trading process to improve one’s position as a buyer or a seller: one is forecasting and the other pertains to strategies and tactics. The two feedback cycles represent a key element in EMPOWER as the local market will be situated in a world that is dominated by amateur traders. To alleviate this EMPOWER seeks to provide software agents that can represent the traders. A central issue has been how much intelligence these software agents require in order to defend the interests of their owners and to assure satisfactory market efficiency and liquidity. A pure ZI agent will not require any learning.

Yet, Gode and Sunder (1993) have shown that ZI agents can adapt to the market and assure satisfactory conduct as long as the rules for operations in the market are complete and properly defined.

4.2 Forecasting

Forecasting can be useful for determining inventories, future demand and supply as well as prices. All can be very important for the decision making that relates to a specific future transaction. Advanced statistics have long been used for forecasting. Good forecasts can be absolutely essential to reduce the risk in the forward market. The longer the time horizon the more important the role of the forecasting process becomes in order to reduce the risk. Yet, the prediction challenge gets harder. As noted by Ampatzis et al. (2014) the successful operation of forward markets and day-ahead markets is strongly dependent on the accuracy of production and consumption forecasts. Within a local market where a number of prosumers operate it is difficult to make accurate forecasts on generation and household consumption. In this respect trading far ahead in time could expose the market agents to too high penalties (Ampatzis et al. 2014). Furthermore, as the time between forecast and execution increases, more inaccuracies must be accounted for. From this often follows the need for additional contingencies. Advanced statistical methods, such as auto-regressions (e.g., ARMA) have typically been used for forecasting development in the energy markets in the past. More recently, machine learning techniques such as neural networks have been adopted (Shahidehpour et al. 2002).

4.3 Bid/Ask

Bid/Ask constitutes a pivotal part of the trade concept that this deliverable is addressing. Bid/Ask specifies any interaction between sellers and buyers. A whole array of interactions are included here, ranging from pure shopping, to negotiations, auctions and cooperation. Many of these can be explained by means of game theory. In EMPOWER the community concept was introduced in D6.1. It suggests that we foresee a trade that is not entirely focused on self-interested agents.

4.4 Clearing

The market clearing process defines the final price or monetary value assigned to a security or a commodity such as energy. This price is determined by the bid and ask process of buyers and sellers interested in making an exchange. In its simplest form the clearing price is predetermined and fixed. The only alternative for the buyer or seller then is to seek other agents that can offer a different price. The role of a market maker includes alleviating issues pertaining to more rapid clearing. A fragmented marketplace will very often encourage a fixed price strategy. Fixed prices are not uncommon in the service market. Some predetermined prices might be negotiable to some degree, unless one party finds himself in a unique selling or buying position.

4.5 Settlement

Settlement implies that a trade agreement has been established between a seller and a buyer and that payment must be committed. It follows the clearing process and might be carried out as a part of it and stretch across both execution and the reward part where the seller's account is credited. Settlement is usually taken care of by an independent third party. Basically it means that a buyer must transfer a payment to a clearing house. This is typically done by the clearing house or a broker that holds the money until the seller's obligations' are met. The settlement has to be carried within the different types of markets included in the EMPOWER market design concept. As an example, Zhang et al. (2013) describe the operation of a flexibility clearing house that is to provide clearing and financial settlement in the flexibility market. In some markets a clearing house may require that traders maintain a minimum amount in their client's accounts to reduce its own risk. In EMPOWER this task should be attributed to the SESP.

4.6 Execution

Execution means that a transfer of ownership of a property or a commodity takes place or that a service is executed. For EMPOWER it implies that specific signals will be sent to the control cloud to assure that the trade is realized (see also D3.2 for this). Realization can be a matter of active control and/or specific metering across a specific period determined by the transaction settled.

4.7 Fulfilment

Fulfilment relates to the successful transfer of ownership or conclusion of a service. This, in turn, signals that the seller has successfully delivered what was promised. In the context of EMPOWER it means that accounts can be updated. This signal will be emitted from the control cloud.

4.8 Reward transfer

As described above the seller's account is credited. However, if discrepancies in volume or quality were noted the cost to alleviate such problems might be deducted from the original amount settled on. In the context of EMPOWER we will apply the term "rewards" as we anticipate the need for a non-monetary credit assignment, too. Rewards for active trading and precise deliveries will be important to drive trade. Non-monetary rewards or what we call "reputation credits" can help to build incentives and grease the wheels of local trade. It can be used to determine ranks and resolve conflicts in auctions where equal bids meet an ask (or vice versa). It might be used to determine annual bonuses or other favours, or it might be applied to yield future price discounts.

4.9 Learning

Learning synthesizes all the experiences from the previous steps. It fuels the feedback process. An essential aspect is representing the new insight in such a manner that it can be exploited both for forecasting and policy changes in the actual bid/ask process.

Services and energy can be traded simultaneously or sequentially. The process is basically the same in each instance. However, the bid/ask part can vary considerably. Auctions constitute the most common form of energy trading. Services in general, however, are often traded bilaterally without any auction and sometimes at a fixed price. But in the energy domain "ancillary services" have typically been subject to auction trade. Ancillary services constitute a special form of services in central energy markets. They are used to facilitate the basic trade and to assure balance between demand and supply in the energy system at all times. Ancillary services include regulation, contingency reserves, spinning, non-spinning and sometimes supplemental reserves. The local market will replicate some aspects of this and will be generally referred to as flexibility services. It is worth noting that in regulated markets ancillary services and energy have typically been bundled, while in deregulated markets they have not. The process described above can be organized in parallel or in sequence for ancillary services. The sequential approach involves a string of computations in energy and ancillary services markets in which the results of one market would represent the starting point for the next market. The TSO plays an important role in balancing supply, demand, and prices in a sequential auction market structure.

The simultaneous approach involves the concurrent computation of supply, demand, and prices in all auction markets, including the service market. In a simultaneous auction market, the TSO would not re-dispatch the generation in an already closed market to adjust the second auction market. According to Shahidehpour et al. (2002) a simultaneous approach would simplify auction market processes and reduce auction market prices due to the integration of energy and ancillary services markets. This relates strongly to core arguments presented in D6.1 for local energy markets.

5 Trading models for local markets

5.1 Introduction

Previous literature focuses on various types of trading models that are relevant for local markets. The models could be moderated and partially or fully adopted in the operation of the energy, flexibility services and other services markets that jointly define the local market in EMPOWER. This section reviews key trading concepts proposed for smart grid oriented power systems and local markets in particular. The concepts introduced are to be capitalized on in the process of defining in detail a widely applicable local market structure that can be accommodated at the centre of the market defined in D6.1. Table 3 in Section 5.2 summarizes the important trading concepts to be further considered in the trade specification effort.

5.2 Trade mechanism and market design

The aim of this section is to specify and synthesize studies that represent concepts of high relevance for developing the EMPOWER local market design. Exploring the theories presented in previous studies will assist for building a consolidated and realistic model for local energy trade. Further on, investigating and comparing theoretical trading concepts is a helpful tool for constructing a local market design that can successfully operate under different market environments. The overview presented in Table 3 below reflects on the various sides of the trading mechanism and market design and addresses the variety of trading alternatives.

When it comes to energy market, auctions are the most often discussed trading alternative. A number of studies have focused on the application of an auction-based trade within the energy sector. A few imminent studies which consider the local perspective are selected. The focus is kept on local market issues related to trade mechanism and market design, with the exception of the iPower system that addresses a centralized flexibility market. Despite its lack of local focus we have included it in our review as it pays attention important concepts that can be adapted for the benefit of a smaller community and its local DSO[7] .

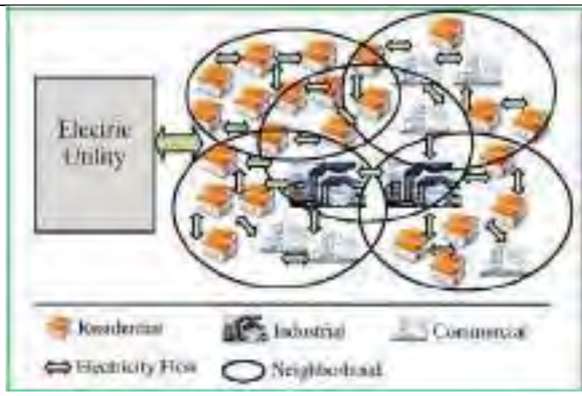
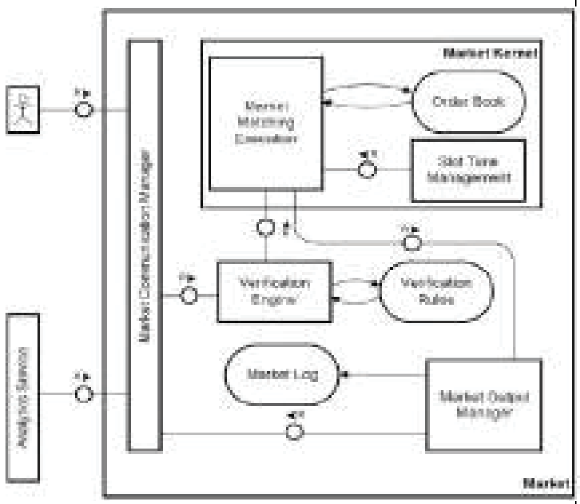
Although the table reflects various characteristics of the trade mechanism and market design, some common issues of concern discussed in more than one study can be specified. Among the most central ones is the choice of trading procedure – electricity auction (e.g., a continuous double auction (CDA) where agents can make offers continuously on the market and improve upon these until a transaction is possible (Vytelingum et al. 2010)) or bilateral contracts. Other key discussion points are the choice of trading horizon (real-time, day-ahead, 15 min time slots, etc.), forecasting, bidding strategies of the market agents, use of smart grid technology, stakeholders' interactions, optimization of outcome and performance measurement.

Table 3: Overview of studies to consider the local market perspective in their modelling procedures

STUDY	TRADE MECHANISM	MARKET DESIGN		
Vytelingum et al. (2010)	Each node in the electricity network can contain buyers or sellers (e.g., individuals, whole neighborhoods or generators). The agents aim to buy or sell electricity on a **day-ahead basis.** This concept uses a **congestion pricing scheme** for electricity flow in transmission lines Trade is based on **CDA:**	**Trading mechanism** (dictates the rules of interactions of the agents trading in the system) - Quote- accepting policy (how to decide which offers to be accepted and which rejected)	**Security mechanism** (computes the flows generated in the system by each trade and informs the market mechanism of the transmission line charges for every trade in the system)	**Balancing mechanism** (uses information generated within the market mechanism to settle prices for extra demand and supply intraday in real-time) Deviations in supply and demand are presented as

[7] See also a first introduction to this in D6.1

	- Limit order (buy or sell with a price constraint) - Market order (buy or sell an exact quantity at any price or nothing at all) - Bid and ask order books MAS system	- Market clearing procedure (the market clears continuously as best matches are being found) - Information revelation Policy (orderbooks and transaction prices are made public)	The security mechanism determines the secure quantity that the network can handle between 2 nodes with respectively bid and ask.	market-order bids and asks and are placed at the top of the bid and ask orderbooks respectively (because these traders have to buy and sell at any price)
Kahrobaee et al. (2013)	Trade outcome depends on 3 different **evaluation metrics** aiming to improve the state of the grid/households: - Demand Deviation (evaluates the mean fluctuations in the overall electricity demand: lower values preferred) - Diversity factor (diversity of the home peak demands: lower values preferred) - Home Cost of Electricity **Assumptions** concerning customers' trade with the grid: - Two electricity rates defined for each hour (purchase rate and a lower rate at which electricity can be sold to the grid) - Real-time pricing scheme - Limit on the amount of power that can be sold to the grid at each hour	**Multi-agent system**: individual homes are autonomous agents making rational decisions to buy, sell or store electricity. The decisions are based on the expected utility provided. The homes are smart and flexible and can interact with the grid in a way that is most beneficial for them. In each hour agents will encounter either **generation deficit or generation surplus.** How to handle the situation will depend on the associated expected utility. **Random models** are used to present the diversity of loads and the households' short-term predictions of the load, generation and electricity rates. Several case studies are compared to account for the **diverse load, generation and storage characteristics** of household agents.  Figure 5.2-1: Electricity flow between different sectors connected to a smart home, Source: Kahrobaee et al. (2013)		
Kahrobaee et al. (2014)	Customers are allowed to trade electricity within their neighbourhood in order to minimize their electricity costs. A **demand flattening management scheme** for the customers is proposed. The impact of the neighbourhood power transactions, demand diversity, and load shifting on the customers and the utility is investigated. Two **performance metrics** are being defined:	**Agent-based market model** that investigated different types of customers and the interactions with their neighbours given a smart grid environment. The study develops a **demand side management strategy** for the customers that allows the utiilization of distributed generation and storage, shift of peak load as well as electricity trade among neighbours. Different case studies are investigated where customers were of various kinds (residential/industrial/commercial) and in possession of different technology (distributed generation/storage). Results indicate improved system performance of the neighbourhood trading. In addition the diversification in the customer group and availability of distributed generation/storage increases the effectiveness of the trade among neighbours.		

	- From the <u>grid perspective</u>: *electricity purchase rate* (reflects the amount of electricity demand from the grid) and *demand factor* (captures variations in the total customer demand) - From the <u>customer's perspective</u>: electricity cost of a customer (the levelized costs of the battery and distributed generation per unit of time) MAS system	 Figure 5.2-2: Main demand side componenets within the smart grid and their electricity flow intercations, Source: Kahrobaee et al. (2014)
Ilic et al. (2012)	Neighbourhood oriented trade **Stock exchange model** Trading periods are discrete **fixed-sized time slots** of same length. Each slot consists of trading and delivery sub-slots Participants can predict their demand/supply at all time slots and also place a market order at each time slot Orders can be adjusted until trading sub-slot closes. An order consists of volume, price and type (buy or sell). MAS system	The local market concept has been realized within the NOBEL project (at the city of Alginet, Spain). Participants at the neighbourhood/district level are given the opportunity to take advantage of local conditions and consume locally produced electricity. The market is being implemented through a market architecture that includes the following key elements: market communication manager, verification engine, market kernel module, order book and order matching, market output manager.  Figure 5.2-3: Interaction of market elements, Source: Ilic et al. (2012)
Bayram et al. (2014)	The study reflects on distributed energy trading concepts in a smart grid. The authors provide overview of the trading models used in the literature and categorize those in a table form (Table 5.2-1). Table 5.2-1: Trading models applied in the literature with respect to the availability (Yes/Y) or unavailability (No/N) of renewables, energy storage systems (ESS) and EVs, Source: Bayram et al. (2014)	The specific features of the market design depend on the enabling technologies included (renewable generation, energy storage, electrical vehicles and communication systems). Microgrid architectures are considered key enablers for optimizing the local operation of distributed renewable energy sources. In this respect Bayram et al (2014) discuss the possibility of prosumers (as part of the microgrid) to interact with each other and trade over a marketplace.

RnwbL	ESS	EVs	Model
Y	N	N	Double Auction
Y	Y	N	Stochastic Optimization
N	N	Y	Noncooperative Game
Y	N	N	Social Welfare Max.
N	Y	Y	Double Auction
N	N	Y	Noncooperative Game
Y	Y	Y	Stackelberg Game
N	N	Y	Stackelberg Game
N	N	Y	Double Auction
Y	Y	Y	Bidding
Y	N	N	Convex Optimization
Y	Y	N	Particle Swarm Optim.

In addition, Bayram et al (2014) provide a generalized classification of the trading frameworks in the following three categories:

- **Game theoretic approach** (e.g., in the presence of multiple interacting agents who try to optimize their own utilities)

- **Single objective maximization** (e.g., in the case of a single user or a central controlling entity that dictates decision to a group of users)

- **Simulation-based solutions** where statistical learning algorithms are used

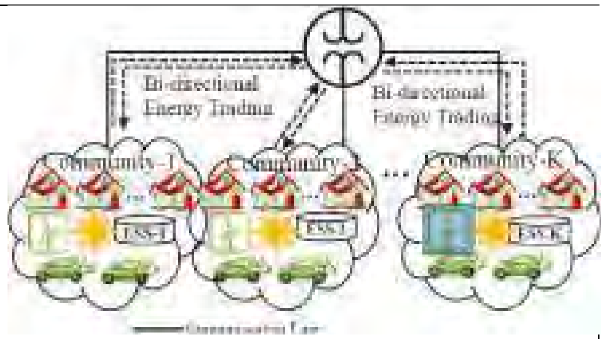


Figure 5.2-4: Energy trading among community based microgrids, Source: Bayram et al. (2014)

Nanduri and Das (2009)

This study discusses important parts of the energy trade:

- Price forecasting is considered an instrument that can help market participants to hedge themselves against the risk of profit volatilities. The **price forecasting methods** that Nanduri and Das (2009) discover in the reviewed literature are: neural networks, fuzzy logic models, time series models and econometric models.

- Electricity auctions are described as complicated due to fluctuating demand and the necessity to meet it at lowest cost by coordinating suppliers with different price characteristics. Two commonly used electricity market auctions: **uniform price auction** (all selected suppliers are paid a uniform price equal to the market clearing one) and **discriminatory auction** (suppliers paid according to their own bids)

- Bilateral contracts represented as classified into: **physical contracts**, **contracts for differences** and **future contracts** with **call** and **put options**.

Nanduri and Das (2009) provide a detailed review of several energy market aspects that previous literature has kept strong focus on:

- **Price forecasting**

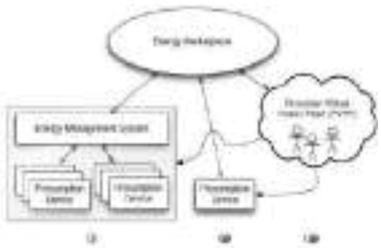
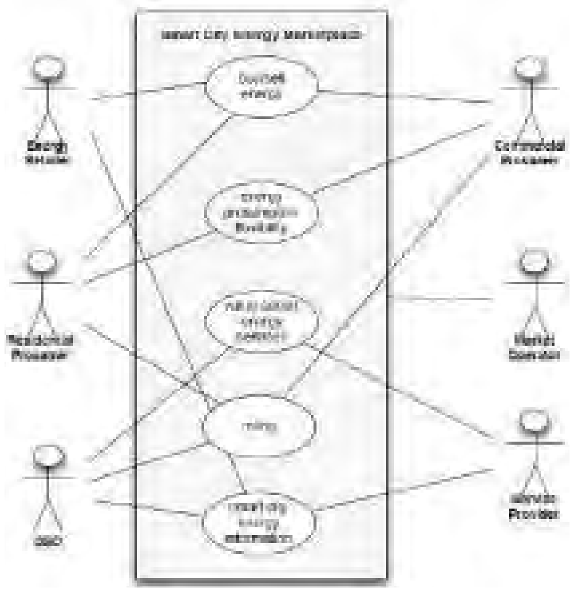
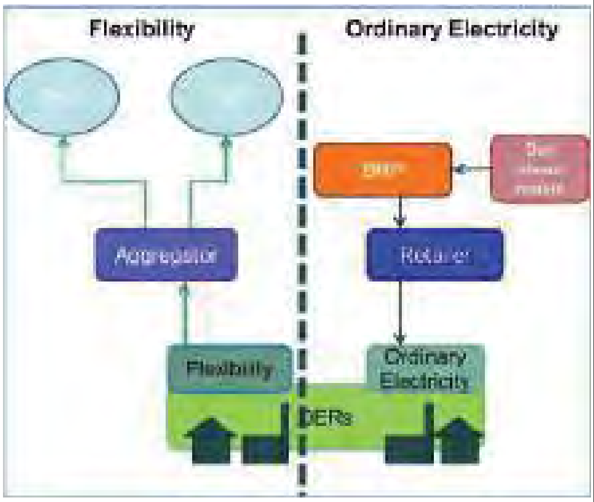
- **Bilateral contracts**

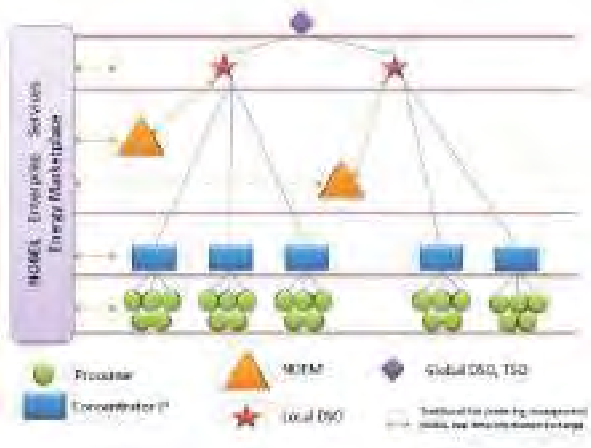
- **Auctions and bidding**

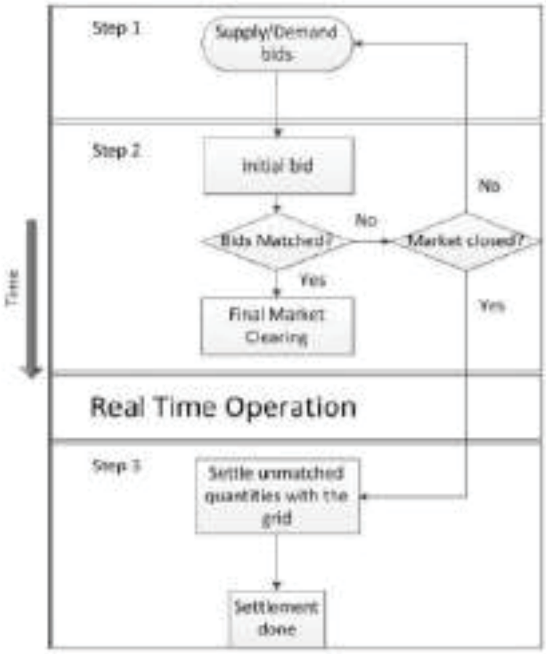
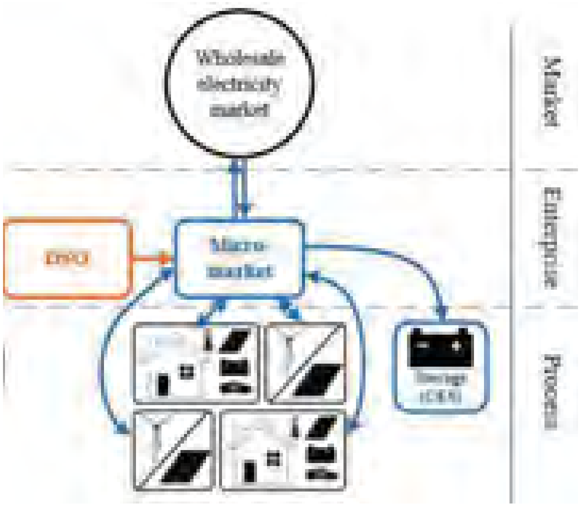
- Determination of **optimal bidding strategy and Nash equilibria**

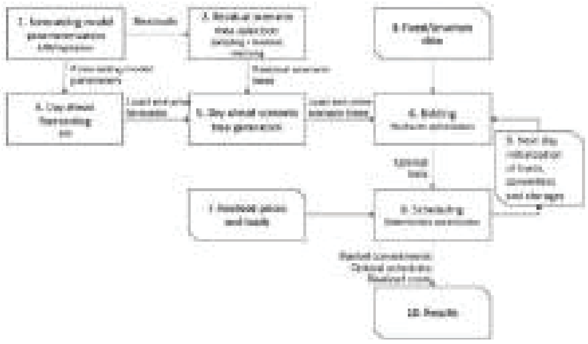
- Mitigation of **market power**

The authors suggest the necessity of developing multi-objective models with specific focus on risk constrained economic and physical power system reliability. Important factors in this respect would be risk management and risk mitigation with respect to electricity market operation, plans for capacity expansion, emissions regulations and operations of the energy, transmission and ancillary services markets.

Karnouskos (2011)	Trading of energy within a neighbourhood marketplace would require: - **Monitoring** (in real time; investments in smart meters needed) - **Management** (control of the prosumer side) Prosumer devices need to be integrated within the local market operations and should be capable of reporting production/consumption or adjusting energy presumption with respect to e.g., price signals.  Figure 5.2-5: Possible prosumer device interaction within the local market, Source: Karnouskos (2011)	An energy market is seen as a possible direction towards easing the interactions among smart grid stakeholders within a smart city.  Figure 5.2-6: Interactions between key stakeholders active in a local marketplace, Source: Karnouskos (2011)
The iPower Project, WP 3.8 (2013)	**Various flexibility services** for load and voltage management offered by the aggregator **Pricing** on the various contracts typically depends on payment for the entire contract period and/or payment per activation Possible trading setups: **bilateral contracts, auction, supermarket** Need for **Flexibility Clearing House** (FLECH) where flexibility can be traded through standardized, controlled and regulated contracts. FLECH can prevent situations where the delivery of flexibility for the TSO creates problems for the DSO, and vice versa. Furthermore the use of FLECH can reduce the risk of malicious behaviour by the aggregator.	Each market player is driven by the possibility to achieve benefit from own supply or demand of electricity services. The flexibility at the consumers' premises could be utilized via an aggregator – a commercial entity that aims to make profit by aggregating flexibility and selling it to the highest possible bidder (e.g., DSO or TSO). The aggregator is expected to have thorough knowledge about the electricity markets and thus be able to trade flexibility most efficiently.  Figure 5.2-7: Possible setup where the electricity and flexibility market operate simultaneously, Source: The iPower project (2013)

The NOBEL project (Karnouskos (2011))	Prosumers to be able to use **brokering capabilities** provided by the **enterprise services**. They will be able to buy or sell electricity in the local market and this will be mainly done via mobile devices through **specially developed applications.** Energy efficiency and intelligent energy management are outcomes of the interactions among local agents and market participation – i.e., there is no centralized responsible body to apply a global strategy. Efficiency of trading outcome can be identified on several levels: - **Smart devices** (functionality of an event-enabled service) - **Concentrator** (acquires and processes information from multiple devices) - **Enterprise system** (could make intelligent queries within the network; these could be processed partially on the concentrator and partially on the device)	Better energy management on local level through integration of enterprise services and prosumer interaction; surplus energy can be traded on an energy marketplace. Local public infrastructure (e.g., public lighting system) can be used to better balance local energy needs or offer flexibility over the local market.  Figure 5.2-8: The NOBEL approach for supporting neighbourhood energy trading and management, Source: Karnouskos (2011) (Note: NOEM is the electricity monitoring and control system within the NOBEL project)
SmartHouse/SmartGrid project (2011)	Need for **short-term (intraday) energy trading** options – i.e. products closer to real-time, consisting of shorter time blocks or event-based. This is facilitated by customer-interactive in-house technology which provides energy management for smart houses using **real-time information** such as **dynamic tariffs** and **metering data**. **Flexible appliances** should get involved, and it should be possible to manage these in a **plug&play manner**. **Consumer organizations/marketing campaigns** and **"killer-apps"** to enthuse end-customers, gain their acceptance and motivate response. Most people would possibly remain connected to the grid to ensure the constant availability of **back-up supply**.	Aim to introduce a holistic concept for smart houses, situated and intelligently managed within their broader environment. Smart houses are considered capable of communicating, interacting and negotiating with both the utility and the single consumer devices/appliances. Some of the technologies envisioned in the project and that characterize the market design include: - **Interface technology** capable of aggregating smart houses into larger intelligent local networks which interact with the electricity grid - **Agent-based distributed control** which enables the monitoring and optimal control of a large number of consuming and producing devices in a fully decentralized manner - **Electronic market and forecasting techniques** that automatically optimize the operation of clusters of smart houses based on negotiated needs, priorities, and interests  Figure 5.2-9: Connection between the in-house architecture and its integration within enterprise processes, Source: SmartHouse/SmartGrid project (2011)

Ampatzis et al.(2014)	**Distributed market-based control** (the system is being coordinated at the lower level with every node possessing only local knowledge. **Self-interested agents** with **profit maximization** utility functions. The aim of the market operator is to maximize the total surplus of the market. **CDA** with private information **15 min trading horizon** and 15 minutes dispatch intervals. Unmatched bids and asks are being served by the grid. A pilot has been run where the participants were **zero-intelligence agents**.	Aim to examine the appropriate local energy market design so that market-based control is realized to successfully integrate PV generation and energy storage at neighbourhood level.  Figure 5.2-10: Flow diagram of the market mechanism proposed by Ampatzis et al.(2014)
Olivella-Rosell et al. (2016)	**Day ahead micro market** Participants generate their offers and bids and send them to the micro-market operator. The operator sends feasible offers to the day-ahead wholesale market and receives information on the energy and prices matched. Prices are used by the operator to operate the storage unit and to decide set points for participants.  Figure 5.2-11: **Market clearing algorithm** consists of two parts – a first one executed before the day-ahead wholesale market clearing takes place, and a second one that includes the steps taken afterwards. In addition, the market algorithm includes two mathematical models: a single and a multi period problems.	The micro-market is managed by an independent micro-market operator that aims to maximize the profits of the community. The operator executes the clearing algorithm and supervises the micro-market operation.  Figure 5.2-12: Day-ahead micro market structure (Olivella-Rosell et al. 2016)

Ottesen et al. (2015)	**Aggregator** that sells electricity to prosumers, buys back their surplus generation and is capable of controlling their flexible energy units. The aggregator has to make to decisions: - **optimal bid** to send to the spot market - **optimal schedule** for every flexible unit Use of **two-stage stochastic mixed integer linear program**: bidding decision is made at the first stage and scheduling in the second.  Figure 5.2-13: Illustration of the information and decision process (Ottesen et al. 2016) The aggregator aims to minimize the costs for the prosumers in total.	Propose **short-term decision-support models** that handle the bidding and scheduling processes for aggregators which deliver electricity to prosumers with flexible energy units and buy back their surplus electricity. The aggregator can control the flexible energy units at the prosumers. The models' objective is to **minimize costs** by trading in an electricity spot market. It also considers the costs associated with grid tariffs, use of fuels and imbalance penalization. A case study is used to demonstrate the model and an overview of its steps is presented in Figure 5.2-14.  Figure 5.2-14: Overview of bidding and scheduling simulation process (Ottesen et al. 2016)

6 Rules of trade, processes and timing

6.1 Introduction

The following discussion highlights important concepts and structures pertinent for the detailed market design and specification of trade in EMPOWER. A direction for most of this was staked out during task T6.1 and documented in D6.1. Here attention is mostly paid to concepts related specifically to the rules of trade, the trading process and the players in the market and their interests.

As discussed by Ampatzis et al. (2014) the implementation of local markets would be most efficient under distributed (and not centralized) control. As described earlier this conclusion was also supported by Ygge and Akkermans (1999). To produce an optimal dispatch the controller would need to acquire extensive information about the end-users – e.g., related to residential energy storage, individual consumption forecasts, profiles of distributed generation, operating costs, etc. The claim that Ampatzis et al. (2014) make is that an operation process which has to consider all these factors would be more scalable and less intensive in terms of computation and communication if performed in a decentralized manner. This would mean that device agents will be allowed to process their local information and construct their bids to participate in the electricity auction. The auction is to be coordinated by an agent who takes the role of a local market operator (Ampatzis et al. 2014). In D6.1 this agent has been specified as the SESP.

Further on, to optimize the results of trading operations, it is important to decide on appropriate trading horizon and dispatch intervals. With respect to local markets, different time slots have been proposed in the literature: day-ahead trade (Ilic et al. 2012, Vytelingum et al. 2010), hour-ahead trade (Jalia et al. 2012), trade in the scale of minutes (Greunsven et al. 2012, Ampatzis et al. 2014), real-time (Vytelingum et al. 2010, Kahrobaee et al. 2013, SmartHouse/SmartGrid project 2011). The choice of trading horizon will depend on the ambition to achieve a market design where the trading mechanism is combined with a balancing mechanism. This combination is being improved on the shorter and the closer to real-time the trading horizon is. In addition, a shorter trading horizon will be more suitable in situations where the possibilities for achieving good forecast on households' electricity consumption/ production are limited. Long-term trading horizons (such as at the forward or the day-ahead markets) are typically dependent on more accurate forecasts (Ampatzis et al. 2014).

6.2 Trading strategies

6.2.1 Introduction

The following paragraphs relate to the ask/bid part of the trading process described in Figure 17, and what positions each player should take with respect to the others. This touches upon strategies and some tactics. The characteristics highlighted are important design elements for trading agents. More importantly, these characteristics help to identify the requirements for proper conduct in the marketplace and thus the rules to be applied.

6.2.2 Self-interest

Several times in this discourse we have touched upon issues of self-interest and shared interests. This requires a critical assessment. The study of Vytelingum et al. (2010) characterises agents as self-interested. As such the agents may misrepresent their preferences. These could be, for example, the amount of electricity required, the capacity they can supply and the prices they would accept. Ampatzis et al. (2014) present different optimization objectives that characterize the various self-interested stakeholders within a local market. According to their study the consumers' objective would be to minimize the cost of consumed electricity while fully satisfying the demand. Prosumers' objectives would depend on whether demand is partially or fully covered by their own generation facilities. If demand is fully covered then the prosumers will aim to maximize the profit of energy traded at the market. In the opposite case the prosumers' objective will be as the consumers' one: minimize cost of electricity consumed. In addition, Ampatzis et al. (2014) note the possibility for presence of cooperative agents which, in contrast to the self-interested ones, would be willing to sacrifice individual profits for the benefit of social welfare. These ideas are congruent with the community idea discussed earlier and which is accommodated to a variable degree in existing businesses such as shopping clubs and energy cooperatives.

6.2.3 Aggressiveness

Vytelingum et al. (2008) describe a novel bidding strategy where autonomous trading agents participate in CDAs according to their level of aggressiveness. A more aggressive agent is willing to trade off profit in order to improve its chance of transacting. In comparison, a less aggressive agent will aim at more profitable transactions and may gamble its chance of transacting in order to achieve them. Further on, the agents' bidding behaviour is based on both short-term and long-term learning. In the short-term learning aggressiveness is updated after the appearance of any bid or ask in the market which enables the agents to immediately respond to market fluctuations. In comparison, the long-term learning determines the agents' choice of offers to submit after every completed transaction and thus helps agents to adapt to the broader trends of demand and supply. Vytelingum et al. (2008) refer to their strategy as adaptive-aggressiveness. Again, this is important as amateur participants, such as owners of regular households, may not know how to optimize for profits per transaction without exposing themselves to greater risks. Satisfaction may be a better strategy than maximization. Multiple, safe trades may produce more yields in the longer term than a more risk prone strategy. In general, the particular risk profile to characterize the traders' ambitions (risk loving, risk neutral or risk averse) will be decisive for the outcome from market participation and the specific benefits that market participants gain. Within the EMPOWER local market setting the impact will depend on the SESP's ability to engage traders in programs that suit their respective risk profiles.

6.2.4 Bidding under uncertainty

Earlier in this document the importance of good forecasts has been discussed (e.g, Section 4.2). Yet, good forecasts can often be hard to attain, specifically when it comes to a market with a large number of actors each of which has its particular consumption, technology and risk characteristics and when production comes from intermittent energy sources. Uncertainty would undoubtedly reflect on the bidding strategies of the agents. As stated by Boomsma et al. (2014) the problem of optimal electricity market bidding is an optimization problem under uncertainty, given that at the time of bidding the outcome of market clearing is unknown. To formulate and solve this bidding problem a variety of approaches have been used in the literature. Boomsma et al. (2014) reflect on the application of different approaches in previous studies – optimal control and dynamic programming and mathematical programming, and address specifically the problem of coordinated bidding into the spot and the balancing market. In the work of Ottesen et al. (2016) the bidding process, seen from the demand side, has been presented by considering the interrelation between hours and the connection of the underlying physical energy system in the portfolio of prosumers. The authors present a market setting in which an aggregator delivers electricity to the prosumers, receives their surplus energy and trades the net demand into the wholesale market. The aggregator's bidding decisions are made under uncertainty as the price, load and generation characteristics are unknown for the periods in the trading horizon. To solve the bidding problem Ottesen et al. (2016) apply a two-stage stochastic recourse program where the uncertain parameters are represented by discrete probability distributions in a two-stage scenario tree. As the bids are given prior to the actual hour of operation there is always risk of imbalances, e.g., associated with changing weather conditions. Imbalance penalties can therefore be included within the bidding problem, as presented in Ottesen et al.'s (2016) model. Finding a most proper way to deal with the uncertainty related to local market operation may be a challenging task. Fortunately previous literature provides sufficient grounds to define and solve the market actors' bidding problem also when it comes to a local level. Stochastic approximation based reinforcement learning (SARL) (Nanduri and Das 2009) is a case in point. It specifically addresses bidding under uncertainty.

6.2.5 Expected utility

Kahrobaee et al. (2013) consider prosumer type of agents that prioritize their decisions based on the expected utility that these decisions provide. It uses utility functions to model people's preferences. The study describes three utilities that are used by the agents to assign decision priorities: *load utility* that represents the priority of the load to be satisfied at a specific hour relative to other decision utilities; *selling utility* which accounts for the agent's incentive to sell excess electricity to the grid; and *store utility* that reflects the agent's incentive to store electricity. Utility functions help in capturing the consumer/prosumer preferences with regards to volume and time of consumption/production. In general, most consumer decisions aim at maximizing profits or minimizing costs by optimizing their utility functions subject to their own budget constraints in addition to market constraints and terms of trade. However, other types of utility functions that represent preferences for either maximizing or minimizing the volume of trade, minimizing non-renewable energy consumption, maximizing energy storage, etc., can also be formulated. The utility topic is further addressed in Section 7.5.

6.2.6 Choice of trading alternative

Although most of the trading concepts highlighted apply auctions as the basis for trade it does not exclude bilateral trade. This option must be considered. With few and inactive participants the SESP might have to provoke engagement through some form of bilateral contract. In the case of auctions, multiple bidding strategies can be applied. Most authors relate to multi-unit auctions since more than one unit of the same type is auctioned. The default focusses on uniform price auctions, although discriminatory auctions might be considered to mitigate short term risks and the need for instant flexibility, upward or downward. Typically generators or suppliers would seek maximum profitability and increase their bids accordingly. Traditionally buyers would do the opposite. However, it may be questioned if non-professional traders seek similar bidding strategies. A utility oriented inclination, which is highlighted by Kahrobaee et al. (2014), rather than a price oriented bidding strategy that seeks to maximize monetary gain only, seems more relevant.

6.3 Technology to facilitate trading

6.3.1 Forecasting

Forecasting of prices, demand or supply has constituted an essential part of trading as long as it has existed. Traders' ability to interpret signals and spot opportunities or threats earlier than others has always been important. Such signals could stem from weather prognosis, news of political change or qualified guessing of what other traders might do at the next crossroad. Trend analyses based on historical data are used in similar ways. Forecasting will never go out of fashion since information that can determine the future may define the difference between a loss or a gain. One thing is to gain access to information that will help to determine the future. Another issue is to make use of this before others do. The aim is often to beat the market. Some HFT agents in the financial industry have the ability to gather and process enormous amounts of information to make a prediction and act within a split second. Modern ICT has opened new opportunities for many traders and closed some for the more conservative. With the advent of Big Data and more sophisticated data science we are likely to see unprecedented developments. Forecasting can be applied to determine longer term trends or to make a choice between different alternatives in a very short time. Different techniques are used. The more traditional ones stem from statistics and pattern analysis. Newer methods stem from artificial intelligence (AI). The latter has typically been made possible due to increased computer power at affordable prices.

Literature on deregulated energy markets encompassing issues on weather or price forecasts are common. Methods applied include statistical time series methods such as auto-regressive processes (Kristiansen 2012). According to Nanduri and Das (2009) price forecasting has become an increasingly important activity in restructured markets. Both electricity producers and consumers rely on this. Nanduri and Das (2009) categorize present methods in terms of neural networks, fuzzy logic models, time series and Bayesian methods and econometric models. The two first stem from a part of AI often referred to as soft computing and can be complemented with techniques such as expert systems and machine learning.

Forecasting in the context of smart grids has become a popular topic as smart meters and high resolution metering provide a better basis for analysis of historical data. Koponen and Takki (2014) claim that the value of demand response depends much on the predictability of the residential loads. Their approach is based on historical weather data, weather forecasts, day length and weekday, and use a method of load control response that takes both linear and nonlinear dynamics into consideration. Ahmed et al. (2014) have applied both auto-regressive methods and neural networks to the problem of consumption forecasting at individual household level. The purpose has been to schedule storage devices. The work is a part of a project focused on photovoltaic generation with integrated energy storage at household level. Dusparic et al. (2013) apply a form of machine learning called reinforcement learning (RIL). This is a technique that is typically referred to as “model-free”. Agents using RIL learn by trial and error and are eventually able to forecast expected utility of each decision that needs to be made and optimize decision making accordingly. RIL is dependent on an extensive state-space search and is computationally very demanding for non-trivial problems. For large statespaces and novel problems RIL holds a still unexplored potential. Investigations carried out suggest that computers using this technique may outperform humans (Doshi-Velez 2011). Similar claims can be made for deep neural networks (Jones 2014). This illustrates a tendency whereby technology can play an even more decisive role in trade in the future. EMPOWER seeks to exploit this potential.

6.3.2 Infrastructure for trade, execution and fulfilment

To enable trade among the local market agents a diversity of smart grid technologies have to be involved. The technological features should encompass a variety of equipment as well as efficient solutions for trading platform, control system and user interface. In EMPOWER's D3.2 a proposal for the market cloud technical architecture is made. In the referred document the operation of the local market is to be facilitated through 3 interacting clouds: control cloud, metering cloud and local marketplace (Figure 18).

Figure 18: Cloud interactions to facilitate local market operation (Source: EMPOWER D3.2)

Further on, as it has been described in EMPOWER's D6.1, technology is an essential part of the market design. According to D6.1 the generating equipment employed and the technology used for metering, visualization, storage, monitoring and control should be made easy to operate by the energy user himself or the community he is a part of, in particular when full control is assumed. In addition, when considering the local market design it is important to take into account both the available state-of-the-art technologies, but also the possible future development in the technology field.

6.3.3 Automation

Automated processes often represent an essential part of the concepts for local energy/flexibility trading. The benefit and possibilities offered by agents to automate the trading process was discussed at length earlier. Automation has proven its worth in the financial market across two decades and it defines the core of the EMPOWER project.

Among the studies referred to in Section 5.2 automation is a key component within the trading concept presented by the NOBEL project too (Karnouskos 2011). Through intelligent automated solutions spreading across several levels (smart devices, concentrators and enterprise systems) an efficient trading outcome is feasible. Within the SmartHouse/SmartGrid project, automation enables the smart houses' interactions with the grid and market participation. As pointed out earlier Ampatzis et al. (2014) applied the concept of ZI trading agents and concluded that they would suffice for a rational local market. Others have used more "knowledgeable agents" to automate auctions and settlements.

Algorithmic trading systems in the financial market have challenged existing clearing and settlement systems. Upgrades have been required to manage the increased intensity of bids and offers and to enhance previous mechanisms for concluding the sale/purchase. Soaring volumes of trades to settle and execute lead to the need of even more sophisticated upgrades. The financial market could in this respect serve as both inspiration and reference for the technical work that needs to be carried out in WP5 in EMPOWER. A solution that can cater for HFT of energy and flexibility must be taken into account. CDAs with a high time resolution will also require due recognition from the technical side. ICT-enabled automation and agent technologies with the concepts already addressed have the potential of challenging the existing sequential market concepts that have become so familiar since the liberalization of the energy market across the world during the 90s and early 2000.

7 Basic trade requirements

7.1 A game theoretic perspective

Local energy/flexibility trading is enabled by a market that provides the platform for trading by matching buyers and sellers. The local energy and flexibility market is in its nascent stages of evolution as compared to the centralized energy exchange market.

However, much of the theory that is used in centralized energy exchange systems like NORD POOL spot is applicable to local energy trading markets as well. For example, computing and analysing the market equilibrium is a key concept in trading markets that determines the stability, predictability and hence, usefulness of such markets. Aspects, such as optimality and efficiency of the market equilibrium, are useful in studying the social welfare achieved by the market. Since the main focus of local energy markets is on trading between prosumers/consumers, study of reputation systems and trust issues is essential for the smooth functioning of the market. Congestion and capacity issues that arise from local energy trading can be minimized by cooperative game theoretic analysis of the market. Game theory is a branch of economics and political science that aims to mathematically model the interactions between independent rational traders with varied interests. Such interactions are common in complex multi-user intelligent systems such as energy markets. It constitutes a part of general energy economics and have been discussed intimately by authors such as Shahidehpour et al. (2002), Zima-Bockarjova et al. (2010) and Wang et al. (2011).

In this chapter, a brief introduction to market equilibrium models, its optimality, efficiency and welfare combined with other issues such as trust, reputation and cooperation in the market are discussed and related to the task at hand to extract a basis for design in WP6's task T6.3. The chapter is intended to explore the theoretical aspects of the market and its repercussions for local energy and flexibility trading.

7.2 Market equilibrium

Market equilibrium is defined as a state where market price is determined by competition such that the amount of energy, flexibility and other services offered by sellers is equal to the amount of energy, flexibility and other services sought by buyers. The trading concepts analysed and referenced above intrinsically seek such equilibrium. If a market is in equilibrium, the prices will not change unless an external factor changes supply and demand dynamics. When a market is not at equilibrium, market forces tend to move it to equilibrium. Market equilibrium is characterized by three important properties.

1. The behaviour of trading agents is consistent
2. No trading agent has an incentive to change its behaviour
3. Equilibrium is the outcome of a dynamic process

When it comes to competition in energy markets the problem of determining the appropriate strategy with regards to the game theory is often discussed (Nabavi and

Hajforoosh 2014). According to Nabavi and Hajforoosh (2014) the Nash equilibrium point represents the certain and optimal answer to the game theory associated problems. The Nash equilibrium point represents an optimal outcome of a game where none of the players has an incentive to deviate from the strategy chosen, given she or he has knowledge on and has considered the opponents' choice. Being at the Nash equilibrium point, a player will not benefit from changing actions, provided the opponents stick to their strategic choices. A game may result in multiple Nash equilibria or have no Nash equilibrium point. As an example, energy suppliers may consider the performance of other players and seek to find their Nash strategy that will bring them reasonable profit (Nabavi and Hajforoosh 2014).

In classical trading economics, market equilibrium is often equated to market clearing, but in modern economics, this is not necessarily true. For example, housing markets, labour markets and some service markets can be in equilibrium without necessarily clearing the market. This could also be expected for instances of local trade. One of the reasons is that amateur traders might operate in an inconsistent manner. With the introduction of system controlled agents operating on behalf of a residence owner this can be avoided, however other forms of non-conform behaviour could be expected in association with a local market. This should be contained.

In wholesale energy markets such as NORD POOL Spot (both Elspot and Elbas), market equilibrium coincides with market clearing. The competition in deregulated energy markets is studied in Ramos et al. (1999) using the concept of economic market equilibrium. The economic theory of energy markets has been analysed in a competitive equilibrium setting by Wang et al. (2011), taking into account the volatility and physical and operational constraints inherent to transmission and generation. Equilibrium bidding in auctions for joint transmission and energy markets is discussed in Babayigit (2007), where a two-tier matrix game theoretic modelling approach is developed that can be used to obtain equilibrium bidding behaviour of the participants in energy markets.

In local energy trading, the presence of home energy storage systems and electric vehicles provide supply elasticity. This elasticity provides a buffer against sharp adjustments in trading energy prices to attain market equilibrium. Hence, equilibrium analysis is crucial for the development and stable operation of local energy and flexibility markets. Moreover, in the presence of more than one kind of market, equilibrium analysis can be broadly classified into two types, namely, partial equilibrium models and general equilibrium models.

7.3 Partial equilibrium

Partial equilibrium models consider either the energy or flexibility market and assume that the energy market has no effect on the flexibility market and vice-versa. Though questionable it dominates present state-of-the-art.

Partial equilibrium models assume a dynamic process where prices adjust themselves until supply equals demand for one type of market while keeping all factors of all other markets constant. Partial equilibrium is derived by modelling supply and demand curves based on production surplus and utility theory of consumption respectively. In local energy trading, partial equilibrium is separately calculated for energy and flexibility markets. Partial equilibrium analysis for energy markets is further made interesting by the supply elasticity of energy storage. However, under certain circumstances, such as the presence of a volatile flexibility market, partial equilibrium analysis of energy markets may be misleading and result in trading prices that are unstable. A demand, supply and partial equilibrium analysis for Turkish electricity energy pricing has been studied in Ozdemir (2013).

Area pricing in the NORD POOL system is a case in point and reflects issues of partial equilibrium well. The spot market produces an equilibrium that yields the system price. However, that is not the price which will have to be paid by the participants. The real price (area price) is settled later when congestion and transmission issues have been considered. In fact, a few of the concepts for local trade addressed here treat only energy trade, exempt of any congestion issues. Hence, only partial equilibrium is achieved.

7.4 General equilibrium

As an a priori assumption the integral market for services, flexibility and energy defined in D6.1 should honour general equilibrium. This is an ambition, though certain aspects of the service market may not be tightly coupled with energy and flexibility8. General equilibrium models (also referred to as Walrasian equilibrium) consider the behaviour of supply, demand, and prices in a whole economy with several or many interacting markets (energy, flexibility, and other services), by seeking to prove that a set of prices exists that will result in an overall equilibrium. General equilibrium theory contrasts to the theory of

[8] There are some important exceptions. Continuous cost control, online diagnosis, repair and emergency procedures are a type of services that can be tightly coupled with energy generation, sales and demand.

partial equilibrium which only analyses single markets. At general equilibrium, all markets in an economy are in simultaneous equilibrium such that all goods in the market are cleared and as few externalities as possible are left out.

General equilibrium models are usually studied using exchange economies where consumers interact to trade their goods in the market. Simple (pure) exchange economies assume that there is no production of goods in the market, while advanced models can incorporate production aspects. The existence of general equilibrium for continuous markets has been proven by Mas-Colell et al. (1991). Equilibrium analysis in wholesale energy markets has been studied in Larson et al. (2002) and Hanson et al. (2006). In the next section, an overview of a pure exchange economy model for trading multiple goods such as energy, flexibility and other services is provided. The general equilibrium in such competitive markets, referred to as the competitive equilibrium is calculated and the concepts of fundamental theorem of social welfare are presented.

7.5 Exchange economy

Pure exchange economy is a model of trading economy where traders exchange goods without any means of production of those goods (Varian (1992)). Goods have already been produced, found, inherited, or endowed, and the only issue is how they should be distributed among traders and at what price. A case in point is the shopping clubs. They operate according to many of the principles that relate to simple exchange economy. Even though this model abstracts from production decisions, it illustrates important insights about the efficiency of allocations of goods among consumers. The theory of exchange of goods has been subsequently developed to include production as well (Elzen 1993).

Trade in local markets, like the one which is considered here, demonstrates features that comply with principles of exchange economy. Once a solar or wind powered generator is installed it is practically exempt of any operational costs apart from maintenance. The marginal operating costs are nil or negligible. Similarly, flexibility is an inherent part of other energy related behaviours and available basically without further costs.

Exchange economy related to a simple market of the type we are addressing can be illustrated. In the following paragraphs, a simple form of exchange economy with two prosumers and two goods (energy and flexibility) is explained. The two prosumers start with an initial endowment of the full set of goods to be exchanged, that is, the amount of energy and flexibility that they are willing to offer in the market, $[(w^1_1, w^1_2), (w^2_1, w^2_2)]$.

Here, the superscript refers to the consumer and subscript refers to the goods, namely, energy and flexibility. Let the trading prices of energy and flexibility be p_1 and p_2. Trading refers to the division or allocation of $w^1_1 + w^2_1$ and $w^1_2 + w^2_2$ respectively to consumption bundles $[(x^1_1, x^2_1), (x^1_2, x^2_2)]$ among the two traders. The exact processes of division and trading prices are determined by the traders' preferences for energy and flexibility. Appropriate utility functions for each trader, $u_1(x^1_1, x^1_2)$ and $u_2(x^2_1, x^2_2)$, reflect the consumption preferences of prosumers with respect to energy and flexibility. Since utility functions are represented in a three dimensional space, they are usually visualized as contours or indifference curves (lines linking points of equal utility) in two dimensions. Indifference curves for common utility functions used in exchange economy such as perfect substitutes, perfect complements, Cobb-Douglas utility, etc. are shown in Figure 19. In perfect substitutes utility, energy may be substituted by flexibility (or other service) meaning the value associated with buying/selling energy may also be obtained by buying/selling flexibility. As long as a certain value is derived, one commodity can be substituted by the other. In perfect complements utility, value associated with buying/selling energy does not increase with more energy without a certain amount of flexibility. In other words, value for one commodity is derived by complementing it with the other commodity. The Cobb-Douglas utility is a trade-off between the perfect substitutes and perfect complements.

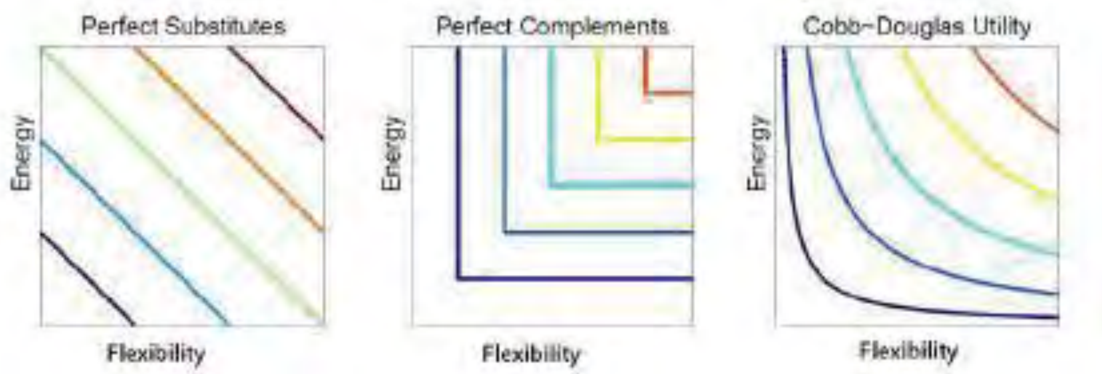


Figure 19: Indifference curves of common utility functions.

The fact that consumers' (in our case also prosumers') preferences and initial endowment are generally different is what makes mutually beneficial trade probable.

Marginal utility (MU) of a consumeris defined as the partial derivative of the utility function with respect to energy or flexibility. It measures the rate at which the utility of a consumer increases as the amount of energy or flexibility is increased. The marginal rate of substitution (MRS) of energy for flexibility is defined as the rate at which energy can be traded for flexibility while keeping the consumer indifferent. The MRS between energy and flexibility is equal to the ratio of the marginal utilities energy and flexibility, or in other words, the slope of the indifference curve. These concepts are illustrated in Figure 20.

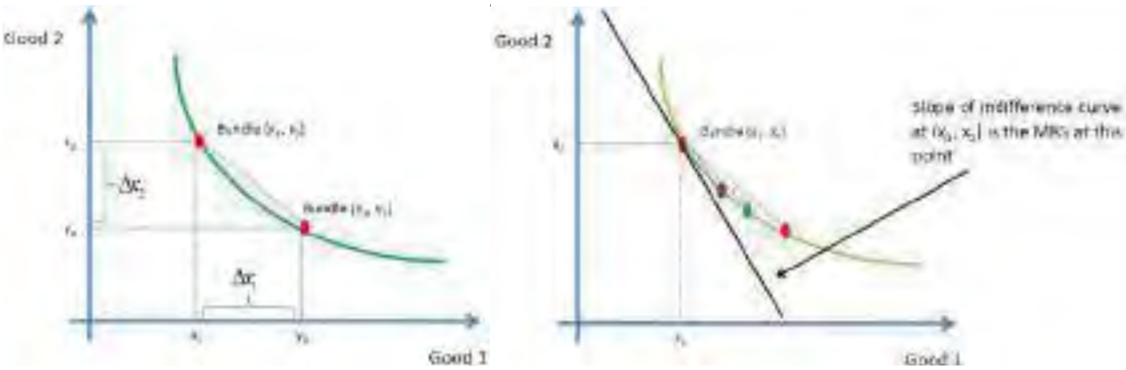


Figure 20: Marginal utility and marginal rate of substitution of goods.

7.5.1 Competitive equilibrium

Competitive equilibrium[9] is the traditional concept of economic equilibrium. It is very useful for analysis of commodity markets with flexible prices and many traders, and serving as the benchmark of efficiency in economic analysis. Most literature on energy markets and local energy markets in particular use competitive equilibrium as a basis for surplus assessments and efficiency evaluations.

At the competitive equilibrium (a set of allocation and trading prices of goods), the market clears itself, meaning, for both energy and flexibility, demand is balanced by supply and the trading prices of goods regulate themselves in such a way that no consumer can be made better off by any further trading without making another consumer worse off.

The competitive equilibrium of an exchange economy must satisfy the feasibility criterion, where, $w^1_1 + w^2_1 = x^1_1 + x^2_1$ and $w^1_2 + w^2_2 = x^1_2 + x^2_2$. It must also satisfy the optimality criterion known as the budget line, where, $p_1w^1_1 + p_2w^1_2 = p_1x^1_1 + p_2x^1_2$ and $p_1w^2_1 + p_2w^2_2 = p_1x^2_1 + p_2x^2_2$. The competitive equilibrium is solved using the following optimization problem.

For each consumer i,

choose a consumption bundle (x^i_1, x^i_2),

that maximizes $u_i(x^i_1, x^i_2)$,

such that $p_1w^i_1 + p_2w^i_2 = p_1x^i_1 + p_2x^i_2$.

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[9] Also called Walrasian equilibrium

The concept of competitive equilibrium can be explained using the Edgeworth box diagram as illustrated in Edgeworth (1881). The novel feature of the Edgeworth box diagram, which makes it different from other diagrams is that it has two origins as shown in Figure 21. The lower left origin is for consumer 1 and quantities for consumer 1 are measured from that origin. The upper right origin is for consumer 2 and quantities for consumer 2 are measured from that origin. The box is bounded by the total amount of each type of good available in the economy. Any point inside the box is an allocation as shown in the figure.

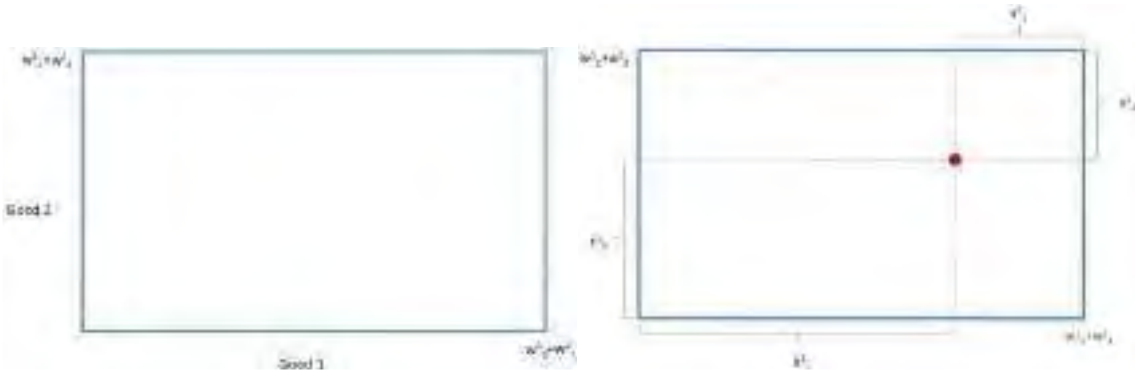

Figure 21: Edgeworth box diagram and an allocation

The optimal consumption bundle for each consumer occurs when the indifference curves of the consumer is tangent to the budget line as shown in Figure 22.

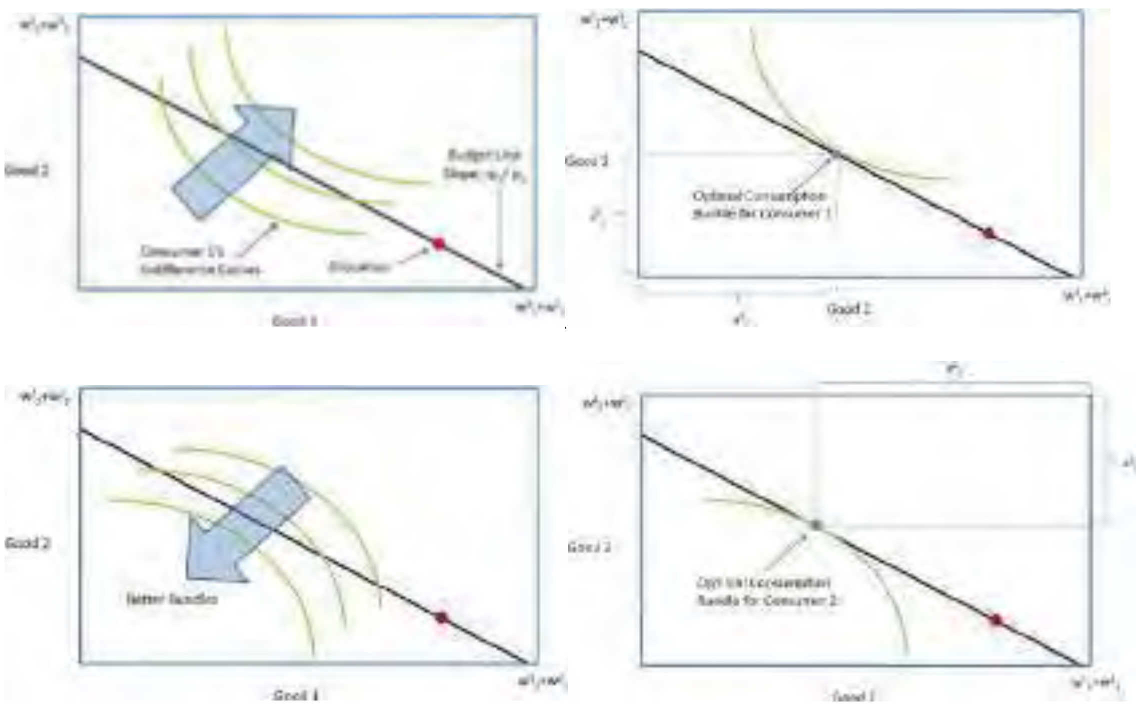

Figure 22: Indifference curves and optimal consumption bundles for two parties. The optimal consumption bundle for each party occurs when the indifference curves of the consumer is tangent to the budget line

The competitive equilibrium is defined as the point where the slope of the indifference curves of user 1 is equal to the slope of the indifference curve of user 2 (as both are equal to the slope of the budget line through endowment point). This means that at competitive equilibrium, the MRS of both users is the same as shown in Figure 23. Moreover, the slope of the budget line at the competitive equilibrium is also the ratio of prices of the goods. The competitive equilibrium gives both the allocation of total endowment and the ratio of prices of energy and flexibility. The Arrow-Debreu model studied in Arrow et al. (1954), confirms the existence of competitive equilibrium in every exchange economy under conditions such as strictly convex consumer preferences, demand independence, desirable goods and perfect competition.

An exchange economy for trading renewable energy and utility provided energy separately in different markets is discussed in Rajasekharan et al. (2013). In this study, the existence of a competitive equilibrium for such markets is established and the ratio of prices for different types of energy is calculated. A complementarity based market model for calculating the economic equilibrium of large power markets such as North American Eastern Interconnection is studied in Hobbs et al. (2003). An exchange economy based model for calculating the competitive equilibrium of hybrid microgrid with solar and wind energy production is studied in Rajasekharan et al. (2014).

In the EMPOWER energy and flexibility markets, the competitive equilibrium can specify the exact amount of energy and flexibility that is to be traded among participants and can also establish a ratio of how participants value energy and flexibility irrespective of the actual prices under the assumption that participants have well defined utility functions for production and consumption of both energy and flexibility. Such utility functions may either be revealed in a straightforward manner to simplify the computation of competitive equilibrium or may be revealed through a bidding process where the market learns the utilities of its traders.

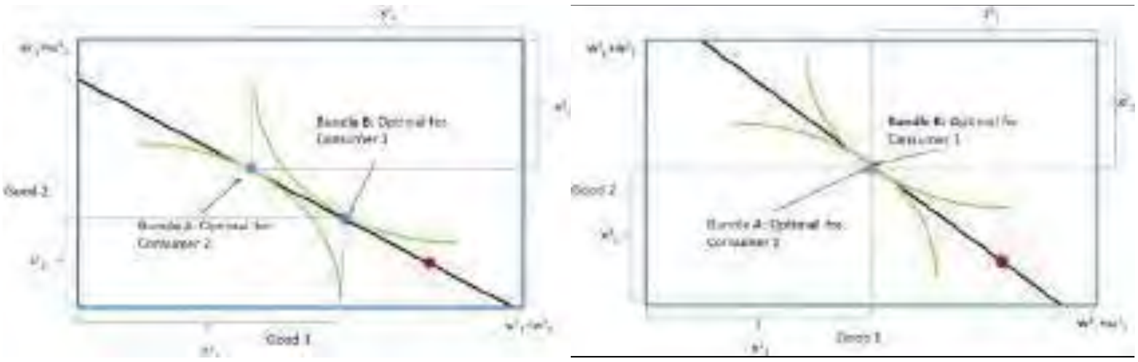

Figure 23: Visualization of competitive equilibrium.

A caveat must be mentioned. This relates to the formulation of the utility and the utility function needed. Unlike the more traditional approaches where price, marginal cost and willingness to pay dominate bidding strategies a more composite expression of utility is required. The example provided address utilities associated with energy and flexibility. It needs to be expanded to take into account the service aspect too. Household consumers relate energy and flexibility to such things as comfort, security and convenience. Utility aspects associated with suppliers should take into account quality aspects related to provisions of clean energy and reliability. Monetary gains can be achieved directly or through the community. Recognition provided by systems such as those implemented by shopping clubs, represents a different kind of currency that makes the utility aspect more complex. On the other side of the equation is the privacy issue and the value and ownership of the data exchanged. All these should be accommodated for in EMPOWER. A utility oriented approach like the one introduced by Kahrobaee et al. (2014) defines a good index point for resolving these issues in EMPOWER.

7.5.2 Optimality, efficiency and welfare

In the previous section, market equilibrium models resulting in stable competitive allocations have been discussed. However, the important question of whether an economically feasible allocation is optimal or efficient or in line with social welfare is essential to the well-being of the market. Optimality refers to best allocation possible in the market, while efficiency aims at targeting the allocations to traders who can gain the most utilitarian value from those allocations. Social welfare here refers to a function that maps the equilibria of markets to outcomes that are desirable, undesirable or indifferent. Social welfare does not pertain to the individual traders in the market, but the market as a whole entity, irrespective of the individual trader's preferences, decisions or strategies. In the context of energy markets, social welfare, optimality and efficiency of allocations for both energy consumers and producers has been discussed in detail by Griffin et al.

(1986) in their book on energy economics and policy. Social welfare in the context of demand response has been studied by Clastres et al. (2015), where it is shown that activating demand elasticity in consumers leads to increased social welfare.

An allocation is Pareto optimal or efficient if the only way to make a consumer better off is by making the other consumer worse off. If consumers' consumption preferences are monotonic, then any competitive equilibrium is Pareto efficient. If consumers' consumption preferences are monotonic, continuous and convex, then any Pareto optimum is also a competitive equilibrium. The set of all Pareto optima is called the contract curve and the competitive equilibrium lies on the contract curve as shown in Figure 24.

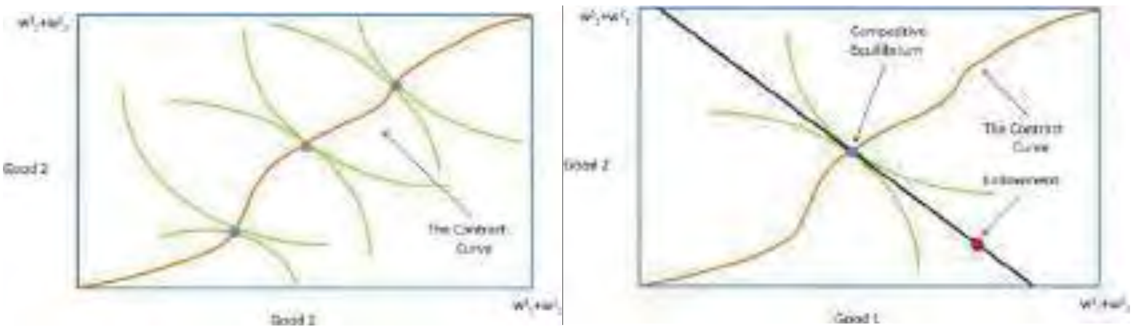

Figure 24: The contract curve and competitive equilibrium.

<u>First fundamental theorem of welfare economics</u> - Suppose there are markets and market prices for all the goods, that all consumers are competitive price takers, and that each consumer's utility depends only on its own bundle of goods. Then, any competitive equilibrium allocation is Pareto optimal. However, one important shortcoming of the first fundamental theorem is that the location of the competitive equilibrium allocation is highly dependent on the location of the initial endowment and is seen as very unfair. Thus, market with traders who trade large amounts of energy and flexibility could skew the market prices in their favour even though the result would be a competitive equilibrium with efficient and optimal allocations. The ability of few participants to maintain prices above competitive levels is referred to as market power.

<u>Second fundamental theorem of welfare economics</u> - Suppose there are markets for all the goods. All consumers are competitive price takers. Each consumer's utility depends only on its own bundle of goods. Suppose further that the traders have convex indifference curves and there is a target allocation. Then, there is a competitive equilibrium price vector which is used to modify budget constraints such that the target allocation is the resulting competitive equilibrium allocation. In the energy trading context, this translates to a social planning where the market is regulated to ensure fairness while

still not compromising on the competitive equilibrium. This guarantees that even small time dealers in energy and flexibility get a fair deal in their trading.

In a more practical context the spot market organized by NORD POOL can be criticized for providing a skewed welfare approximation as no differentiation of energy quality or distance is made. The surplus produced does not reflect the true costs or benefits associated with delivery of renewable energy to the end-user. This tilts the market in favour of larger, centralized units. Fossil fuelled plants are only discriminated in terms of marginal costs, largely determined by fuel costs, not type of fuel. This tends to keep prices lower than they should be. The equilibrium reached is thus based on a higher demand that can lead to higher transportation costs that need to be resolved and paid by the society. The stark difference between consumers' valuation of purchased energy compared to renounced energy (typically through a demand response program) also illustrates the fact that the current central market is unable to capture aspects that are relevant for price setting. The local market cannot afford to exclude such considerations.

7.6 Reward and reputation mechanism

It is the present opinion that local markets embraced by a community will have to apply some means of score taking for active engagement. This has already been explained and must be included in the utility function. Trust development among traders in a market and within the community is required to mitigate uncertainty and risks involved in transactions. This relates to the reward transfer part of the trading process. Any trader in the market would prefer to trade with another trader who has a fairly good reputation for consistent delivery of energy and flexibility as agreed upon during the transaction. Trust facilitation is enabled by reputation systems that help traders decide whether to trade with potential trading partners as well as to gauge the degree of confidence in such transactions. Amazon's product reviews, eBay's feedback score system, Slashdot's Karma System, and Xbox Live's Achievements are all examples of successful reputation systems that provide traders with a decision support framework for market transactions and have been studied in detail by Jøsang et al. (2007). Traders dealing with a regional or specialized product such as energy and flexibility trade, share a common and collective reputation which is based on the trading groups' aggregate quality. The concept of collective reputation is likened to a natural resource extraction process in Winfree et al. (2003).

Reputation systems provide a collaborative method for traders to assess the trustworthiness as well as to predict the future behaviour of other traders based on sharing past trading history and testimonials of trade worthiness. It helps traders choose reputable parties to trade with and avoid dealing with dubious ones. However, designing a reliable reputation system is a challenging task as traders cannot be expected to spend lengthy periods of time to obtain their potential trading counterparts' reputation reports. A reputation system design for online trading communities is presented in Osman and Taylor (2010), where the aim is to design a reputation system with high availability and efficient retrieval of reputation information as well as reasonably reliable deal evaluations and testimonials in order to provide effective ways to facilitate trust development among traders.

7.6.1 Trust

Trust relates to consumers' and prosumers' need for security in life (Bremdal 2015). Trusting the EMPOWER system is essential for engagement. Trust is evidentially founded belief (based on historic records or sources including oneself) that one trader has about another with respect to its reliability and honesty in carrying out trade where there are significant risks of loss to the first party. This definition emphasizes three aspects of trust in the context of a transaction namely belief, evidence and associated risks. Xiong et al. (2003) have proposed a dynamic trust model for peer-to-peer e-commerce communities using a transaction-based feedback system where a trader's trustworthiness is measured based on five factors, namely satisfaction, number of transactions, credibility of feedback, transaction context and community context.

A trust based relationship is established between two traders when both have a belief supported by appropriate evidence that the other party is a reliable and honest party to trade with. Such trust enables the parties to view the downside risks in transactions such as being cheated through non-payment, the traded items not being as described and so on, as acceptable. The supporting evidence could include testimonials of a trader's trustworthiness, history of evaluated trades, digital certificates and so on. A transaction is risky if engaging in it makes traders vulnerable to significant loss in terms of:

- The item being traded - Loss can be incurred if a trader does not get what he has paid for or has received items or money in exchange for goods that are less than promised in the trade agreement.
- Trading opportunities - A trader may lose opportunities to trade with other traders on better terms if his trading counterpart withdraws from their deal or forces inferior terms on the deal under the threat of withdrawal.

- Reputation risks - Engaging in a transaction with an ill-intentioned trader who then provides an unfair negative evaluation after the transaction can damage a trader's good reputation.
- Time and effort - Loss can also be incurred in terms of the time and effort to get to the exchange place if one party does not turn up after making an agreement to do so.

Trust or lack of trust may influence trading in profound ways. A transaction that is potentially risky becomes acceptable if supporting evidence is sufficient for a trader to believe that his trading counterpart or the system is a reliable and honest trader and the likelihood and impact of downside losses are low enough for that trader to expose himself to those risks. In the context of EMPOWER this pertains to user involvement, attractiveness of the community concept and design of bidding strategies.

7.6.2 Reputation

Exploiting reputation is an effective way to encourage cooperation and honesty in transactions. To achieve collaboration in a community and avoid political processes reputation and trust are both essential.

By using past trading history to predict the future behaviour of a trader a reputation can be established. A prosumer that persistently overestimates his capability to deliver surplus energy and must invoke different forms of external compensation may not be the first one anyone buys from in the future. A buyer that fails to pay in time risks a poor reputation. In contrast, a prosumer that controls the energy output so as to meet his obligations may have his reputation excelled. Similarly, a consumer that responds to demand reduction in time may rise in esteem within the community. This reputation and ranking system motivates traders to act honestly in each of their transactions to maintain a sufficient reputation and remain active in that marketplace. Reputation systems have already proven useful in many commercial online applications.

Resnick et al. (2000) study eBay's reputation system in which a buyer can rate a seller by giving a positive, negative or neutral rating and also a short comment after the completion of each transaction. An overall score is computed based on the percentage of the total number of positive and negative ratings that a seller has received for the past 12 months. A buyer can also provide more detailed information about a seller by giving a 5-star rating on the aspects of item description, communication, delivery time and postage and packaging charges. An average rating for each aspect is published. eBay ratings encourage users to engage in transactions offered by highly rated sellers and sometimes allows them to charge higher prices.

7.7 Congestion and capacity issues

7.7.1 Area pricing and buy-back

Liberal trade will be subject to capacity issues. It is always possible that the energy and flexibility trading could be constrained by distribution grid capacity limits or congestion problems. In the wholesale energy market, capacity and congestion problems in transmission grids pose constraints on the trading algorithms and are solved using forward capacity allocation methods. The network code on capacity allocation and congestion management (CACM) adopted by the European network of transmission system operators for electricity (ENTSO-E) provides a framework for dealing with such issues.

In existing, central markets such as NORD POOL congestion is typically managed by means of area pricing and buy-back. As mentioned before area pricing requires a means to settle the full demand and supply prior to resolving capacity issues. This is done in the spot-market. One advantage with this is that it enables accurate capacity calculations. This requires a form of non-continuous trading since the aggregate demand and supply must be established prior to the capacity calculations. Traders run the risk of being confronted with a congestion rent, which can be difficult to forecast and with few hedging possibilities. Differences between the system price and area prices represent an uncertainty that clearly many traders would have liked to avoid.

Demand response programmes represent a form of buy-back and the SESP could be responsible for this on behalf of the DSO. The SESP will then buy on one side and sell on the other. The former means that suppliers are encouraged to increase output and end users to decrease consumption. Selling means the opposite. Buy-back can be initiated instantly as capacity alarms are issued. Continuous trading can be supported. With buy-back in this form a uniform price is possible too, depending on the type of auction that is hosted. Buy-back requires funds to pay out participants for their contributions. This leads to a net cost. However, the SESP can secure a better price by means of futures and forwards. In the context of EMPOWER it should also be possible to combine buy-out procedures with a market making role.

7.7.2 A game theoretic approach

An aid for resolving the congestion issue in local markets can also be related to cooperative game theory. The community concept offers this possibility.

At the distribution side, such constraints must be overcome by consumers forming coalitions to share limited resources. Resource allocation is an optimization technique for sharing limited resources under capacity or congestion constraints. This brings us back to the rationale behind the community oriented approach and the trade-off between self-interest and cooperation.

Game theory can be subdivided into non-cooperative and cooperative game theory. Non-cooperative game theory studies the strategic choices resulting from the interactions among competing traders, where each trader selfishly chooses its strategy independently for improving its own performance (utility) or reducing its losses (costs). However, while sharing common resources, independent rational traders completely acting in self-interest often behave contrary to the best interests of the whole group as demonstrated by the *tragedy of commons* effect in Hardin (1968). In order to overcome the effects of competition that could be detrimental to each other and the group, traders could cooperate in a mutually beneficial manner without compromising on their individual performance. Much of what energy cooperatives stand for can be explained in terms of cooperative game theory. The essence is that collaboration may increase the economic welfare for the collective and in turn the individual, more than the sum of self-interest focused efforts can achieve.

7.7.3 Cooperative game theory

Cooperative game theory is an analytical tool used for modelling cooperative interactions that benefit both the individual players and the group as such. Traders may seek bilateral agreements with other individuals or take part in the open market if the pay offs are better. In the first case the player may wish to act alone or coordinate with others to create a common strategy. In deciding to participate in the market pool, a participant may choose either to *cooperate* with the market (taking the spot price) or *collude* with other participants. Market regulations should prevent any coalitions except the grand coalition and encourage *cooperation* in the power market. The theory behind this can be found in cooperative game theory and can be adapted to the local market concept developed where the community is essential.

Cooperation among energy traders results in the formation of coalitions, where the members of the coalitions are determined by the interconnection and topography of the distribution grid. The main goal of such coalitions is to overcome the congestion and capacity issues arising from large scale trading. By limiting the majority of the trading to localized area, line capacity issues can be circumvented to a large extent. However, quantifying and sharing the benefits of cooperation amongst all agents in a fair and stable manner is a non-trivial problem of great interest. Cooperative game theory provides a framework for quantifying the benefits or value of cooperation and for fairly allocating resources (payoffs) to traders in accordance with their individual and marginal contribution towards the overall value achieved through cooperation. The application of cooperative game theoretic solution concepts to sharing renewable energy hedge pool in Brazil has been studied by Street et al. (2011). The three main renewable sources are wind power, small run-of-river hydro and cogeneration from sugarcane waste. Their highly seasonal yet complementary availability makes individual energy selling through contracts a dangerous option. By taking advantage of the resource mix, the optimal joint risk-adjusted trading strategy creates financial surplus value that is studied using cooperative game theory. The study proposes a risk-averse renewable energy hedge pool to jointly sell a single complementary renewable generation portfolio and analyses different schemes of sharing the financial gains, namely quotas, between the members of such a pool from a cooperative game theory point of view.

Among other works, cooperative game theory strategies have been used for studying intelligent electricity trading systems of power generation companies under the new electricity trading arrangement (NETA) in UK by Yin et al. (2007). Cooperative game theory has been applied to the study of energy markets and system supply planning by Zima-Bockarjova et al. (2010), for group-buying under collective energy tariff schemes by Vinyals et al. (2014) and for formulating cap and trade carbon tax policies in generation expansion planning by He et al. (2012). Thus, cooperative game theory can play an important role not only in terms of capacity management and congestion management, but also as a tool to manage limited resources within a community operating in islanding mode.

8 The basis for EMPOWER trade model development

Considering the references provided in the previous chapters, as well as other studies of relevance, this chapter reflects on important issues that concern the different types of markets included in the EMPOWER market design and their interaction. The following market design characteristics are considered important with respect to the modelling proposals to be specified in D6.3 and will be discussed when relevant in this Chapter 8:

8.1 Organization of trade

The central aspect here is the choice of continuous versus non-continuous trading. European power exchanges typically apply bidding-based trading with contracts for power delivery during, e.g., a particular hour of the next day and the usual trading system relies on a daily double-sided auction where transactions are matched at a single price and a fixed point in time (Madlener and Kaufmann 2002). This is the non-continuous type of trade where participants can submit and change their bids until the predefined closure time. Under a non-continuous trading regime the price is determined by collecting the bids up to closure, sorting and aggregating them, so that the market supply and demand curve for ,e.g., every hour is attained. An alternative form of trade is continuous trading whose three main differences from the non-continuous trade are clearly summarized by Madlener and Kaufmann (2002): participants have access to the orderbook; incoming bids are immediately checked and matched, if possible, according to price/time priority; the contract price for all transactions is not the same. Thus, in contrast to non-continuous trading, continuous trade does not provide a uniform price, but prices contracts either at the offered price of bids, or according to complex rules that consider all bids in the orderbook at the moment of matching (Madlener and Kaufmann 2002).

The matching rules for non-continuous and continuous trading are different as well. While non-continuous trading executes all purchase bids with a price higher and all sale bids with a price lower than that at which the market is cleared, continuous bids are typically matched in accordance to what is being accepted by the opposite side.

The literature does not provide a clear answer as to which trading structure is better suited for a local market. Yet, the choice of continuous trading is somewhat more prevalent in the models related to local markets. One reason could be that continuous trading might be associated with higher allocative efficiency. This could be partially contributed to the matching rule that characterizes continuous trading. As Pancs (2012) shows continuous trade is more allocatively efficient than the periodic auction when asymmetric information is small and when traders are impatient. This can be in particular the case for local market structures.

In Zhang et al. (2013) different trading setups are reflected: bilateral contracts, auctions and supermarkets. The authors suggest that the different setups do not necessarily exclude each other but could rather have a mutually beneficial co-existence. The applicability of the various trading setups would additionally depend on the type of local market described (energy, flexibility or other services) and the market's particular size. Finally, as stated by Nanduri and Das (2009), a comprehensive study considering day-ahead, real-time, financial transmission rights markets, optimal power flow with transmission constraints and supply/demand bidding might be needed to produce definitive conclusions about auction performance.

8.2 Trading horizon and time resolution

Shorter time horizons and time resolution will be important for efficient market operation under the presence of multiple distributed generation units. Section 4.2 has presented two main reasons for that – inaccurate forecasts for loads at the end-user's side and the ambition to combine the trading and balancing mechanisms. Clearly, the nature of the flexibility market presupposes a shorter and closer to real-time trading horizon when compared to the energy market. For the other services market the trade would often depend on predefined contractual agreements.

8.3 Duration and opening hours

A main issue in defining the trade's duration and opening hours is the choice of continuous versus non-continuous trading. While the successful application of continuous trade within a local market has been described in several studies (Vytelingum et al. 2010, Ilic et al. 2012, Ampatzis et al. 2014), the efficiency of CDA has been questioned by Weber and Schroder (2011). According to them when flexibility is costly (i.e. when it costs more for market participants to change their schedules at short notice, as compared to changing the schedules earlier) the efficiency of the CDAs can be negatively affected.

Presently, continuous electricity markets exist in the form of intraday market. However, the results presented by Weber and Schroder (2011) make it uncertain on whether flexibility could be sufficiently exploited through CDAs. And while continuous trading may give good results for the local market, there might be other, more efficient solutions for the flexibility part of it.

8.4 Bidding strategies/policies

The use of different bidding strategies accounts for the diversity of the local market participants and their objectives. In Section 6.2 some key aspects of the traders' strategies have been described. Clearly, the strategy will depend on the specific attitude of each agent (e.g. self-interested vs. cooperative, aiming at profit maximization vs. an optimal level of personal satisfaction). The concept of adaptive aggressiveness described by Vytelingum et al. (2008) refers to the importance of short-term and long-term learning when defining the traders, bidding strategy. Jalia et al. (2012) consider three arbitrary bid strategies (aggressive, anxious and greedy) that reflect the behaviour in the auction process. These strategies are considered as simple linear expressions with slopes increasing from "aggressive" towards "greedy". The ZI strategy described by Gode and Sunder (1993) has been proven less efficient when compared to the adaptive aggressiveness in electricity markets strategy (Vytelingum et al. 2010), but has, however, shown to be sufficient for achieving a logically behaving market (Ampatzis et al. 2014).

8.5 Types of bids

Within the NORD POOL spot market (Elspot) trade is based on three different types of bids[10]:

- Single hourly orders – The participant specifies purchase or sales volume for each hour and may choose between price dependent and price independent order. When the prices for each hour are determined they are compared to the member's order to establish the traded volume for that member.
- Flexible hourly order – The participant specifies a fixed price limit and volume for an order with one hour's duration but the hour is not specified. The order will be accepted in the hour optimizing the overall socioeconomic welfare, given the area price is above the asking price (for a sales order) or below the selling price (for a purchase order).
- Block order – Consists of specified volume and price for at least three consecutive hours:

[10] Detailed description available at: ttp://www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/Order-types/

- Regular block orders – The simplest case of block orders that has an "All-or-Nothing" condition. The order should be accepted entirely and covers all hours and the volume specified.
- Profile block orders – Characterized by different volume in each period over the entire time span. The minimum block segment length is one hour while the minimum order duration is as for regular block orders – 3 hours

Other modifications of market orders, discussed in the document "EUPHEMIA Public Description. PCR Market Coupling Algorithm" (EPEX Spot et al. 2013) are:

- Aggregated hourly order – Orders from all market participants belonging to the same bidding area are aggregated into a single supply/demand curve (piecewise linear, stepwise or a combination of these) defined for each period of the day. While demand orders are typically sorted from the highest price to the lowest, supply orders are sorted in the opposite direction.
- Complex order – Represents a set of simple supply stepwise hourly orders (referred to as hourly sub-orders). It belongs to a single market participant but spreads across different periods. This type of order is subject to a complex condition that affects the set of hourly sub-orders as a whole.
    - MIC order – Complex orders that are subject to minimum income condition constraints.
    - Load gradient order - Complex orders that are subject to a load gradient constraint. This would mean that the amount of energy that is matched by the hourly sub-orders in one period is limited by the amount of energy that has been matched by the hourly sub-orders in the previous period.
    - Combined MIC and load gradient order
- Merit order and PUN order – Merit orders represent individual step orders defined at a given period that is associated with a merit order number. The lower the number, the higher the priority for acceptance. PUN orders are a type of demand merit orders that are cleared at the PUN price (which in the EUPHEMIA's document stands for "Prezzo Unico Nazionale"), and not at the bidding area market clearing price.

In addition, besides the types of block order bids described by NORD POOL above, the EUPHEMIA document proposes the use of:

- Linked block orders – Block orders are linked together and the acceptance of individual block becomes dependent on the acceptance of other block orders.
- Block orders in an exclusive group – A set of block orders for which the sum of the acceptance ratios cannot exceed 1. If in the group there are blocks with a minimum acceptance ratio of 1, then at most one of the exclusive group's blocks can be accepted.

The presented summary of types of orders is meant to provide overview of basic bid features that can be further modified and used within the development of the EMPOWER trading concept in task T6.3.

8.6 Clearing principals and residual handling

Clearing principals would depend on how trade is organized. For example, in the case of uniform price auction there would be one market clearing price for all transactions and this is the equilibrium price derived from the aggregation of demand and supply bids (Ampatzis et al. 2014). Discriminatory auction, on the other hand, would mean that each transaction has a different trading price that stems from the supply and demand price of the matched bids (Ampatzis et al. 2014). In Vytelingum et al. (2010) CDA is applied and market clearing is carried out continuously – whenever the state of the orderbooks changes (e.g., through a new offer entering or an existing offer being improved on) the market attempts to clear by finding the best match in the orderbooks. Further on, Vytelingum et al. (2010) use a balancing mechanism to deal with the unmatched residual bids and asks from buyers and sellers still willing to trade during real-time. These residual bids and asks are placed on the top of the orderbooks and are cleared by considering that the respective traders are now willing to buy or sell at any price. In addition, in Vytelingum et al. (2010) congestion concerns are considered through a security mechanism that determines the feasibility of a transaction between a buyer and a seller and what transmission line charges should be applied to it. In general, the choice of continuous vs non-continuous trade will mirror into different principles for market clearing. While non-continuous trade is associated with pay-as-cleared (uniform price) market clearing, continuous trading would result in a pay-as-bid (discriminatory) clearing.

8.7 Market power mitigation

Market power is an individual's or group of individuals' ability to profitably maintain prices above competitive levels for a significant period of time (Federal energy regulation commission (2002)). Since electric power prices are intended to guide the efficient dispatch of generation resources involving multiple technologies and fuel types, as well as investment in transmission facilities, a distortion in power prices can alter production and investment decisions in a manner that creates substantial additional inefficiencies. While the mere possession of market power is not illegal, abuse of market power ultimately harms consumers by substantially distorting or impairing competition. This is not in the economic interest of the market participants. Hence, market power mitigation techniques have been employed by power exchanges all over the world.

Reitzes et al. (2007) assess centralized power markets in the USA, UK, the Nordic countries and Australia and provide an overview of the market mitigating schemes used. Nanduri and Das (2009) propose encouraging investment in generation, introducing bid price caps, preventing capacity withholding, avoiding transmission congestion and educating the consumers. NORD POOL has established a market surveillance department responsible for monitoring the power exchange's physical and financial markets. Nord Pool relies mainly on market conduct rules and *ex-post* enforcement mechanisms, where its markets are monitored for potential abuses that are addressed after-the-fact through an investigative process and fines. Many of the market power mitigation practices followed by central power exchanges may be equally applicable for local energy markets as well.

8.8 Desired outcomes

Previous studies apply different ways of modelling the desired outcome from local market trade. Nanduri and Das (2009) define some of the challenges related to deregulated electricity markets which can also be considered as desired outcomes: alleviating congestions and related locational price spikes, maintaining system reliability and mitigating market power of the participants. Within the NOBEL project the target of local energy trade is to improve the energy management at neighbourhood/district level. This is expected to happen through the integration of enterprise services and prosumer interaction, while surplus energy is to be traded on the marketplace (Karnouskos 2011). The particular desired outcome in Vytelingum et al. (2010) is a scalable and efficient electricity market that is resilient to failures related to transmission line congestions and to dynamic demand and supply. According to Ilic et al. (2012) the aims of local market trade can be associated with reduction of energy transmission costs, improved integration of renewable energy resources, stakeholder benefits and, in general, a better way to manage volatile networks. Bayram et al. (2014) present the expected benefits associated with energy trading in smart grid: improved system efficiency (e.g., through meeting demand locally and thus reducing congestion in transmission lines), reduced system operation costs (when energy is traded locally during peak hours), reduction in GHG emissions (as the use of renewable generation is optimized), energy profiling (through focusing on the efficiency of local production, consumption and trade). Other defined forms of desired outcome, as presented in the literature discussed are: minimize power costs and alleviate the overall peak load of the system during operation (Kahrobaee et al. 2013), achieving market efficiency and realization of market-based control (Ampatzis et al. 2014), utilize DER as economically efficient as possible through a flexibility market and satisfy the DSOs' requirements of congestion management (Zhang et al.2013). Ottesen et al. (2016) describe a two-stage stochastic optimization model where an aggregator aims to minimize the total cost for electricity prosumers by means of controlling their flexible energy units and buying/selling electricity on their behalf. Such a setting is highly relevant for the flexibility part of the EMPOWER local market. As a whole, the desired outcomes referred to in the studies span from achieving objectives at the end-user side (e.g., maximizing benefit/utility) to power system objectives (such as reduced costs of operation/improved efficiency).Thus, the final EMPOWER trading concept might use different optimization objectives for the different parts of the local market (energy, flexibility and other services) as well as for the different timely stages within the specific market structure's procedures.

9 Models for the EMPOWER trading mechanism – a design basis

A starting point for the models to be presented in this chapter will be the basic EMPOWER market design.

Figure 25: The basic EMPOWER market design in the sub-case where the SESP coordinates the local market and interaction with the wholesale market is possible (Source: EMPOWER Deliverable 3.2).

The models presented should therefore not only reflect on the possibilities for local trade, but also on their specificities when the three different local markets (energy, flexibility, and other services) operate side by side.

9.1 Model 1

Model 1 (M1) is based on the local energy market concept presented by Vytelingum et al. (2010). The energy price is the sole value reference. The trading mechanism is relying on CDA (Continuous Double Auction). Thus, participating agents can make market offers continuously and improve upon them until a bid and ask are matched. The implantation of a CDA is of highest relevance for the local energy market but it could be applied for the local flexibility market as well, while for the other services market different types of trading procedures would be more suitable.

With reference to Vytelingum et al. (2010), in M1 the system is composed of a set of agents who can be both buyers and sellers. For the local energy market, predominantly based on electricity, these can be denoted by $b^e \in B^e$ and $s^e \in S^e$, for the flexibility $b^f \in B^f$ and $s^f \in S^f$, and for the other services market $b^s \in B^s$ and $s^s \in S^s$,. Further on, the electricity network is composed of nodes n^1, n^2, …$\in N$ and a transmission line consists of pairs of nodes $t = (n, n')$ where $n, n' \in N$. Each buyer is characterized by its fixed electricity demand and a cost function that defines how much the buyer is willing to pay for a given quantity that is above the fixed demand. Similar are the characteristics for a seller – a seller's cost function indicates the amount at which it is willing to sell a certain quantity. The maximum amount of electricity a seller can provide is additionally defined.

An important assumption is that transmission lines are owned and maintained by a network manager who applies congestion pricing on the transmission of electricity. Each transmission line is being assigned a price function that is constrained by the maximum transmission capacity of the line.

The optimal allocation of resources in the network is typically computed based on the cost functions specified for all agents. These functions are assumed reported and the model represents a convex optimization problem where the system's efficiency is maximized based on constraints in the transmission lines. Yet, for the particular application of Vytelingum et al.'s (2010) concept for the purposes of the EMPOWER market design it is necessary to look into the concept's relevance for the three different markets included

- **The local energy market**
    - The energy market operates through a CDA
    - Traders submit 2 types of offers:
        - → Elastic limit order (where a price constraint is set)
        - → Inelastic market order (where the quantities are fixed)
    - Information is made public to all participants through the bid and ask orderbooks

As the market clears continuously whenever bids and asks are matched, the unmatched bids are placed in a bid orderbook and are queued first by decreasing bid prices and second by earliest arrival times. Similarly, the unmatched asks are placed in an ask orderbook where they are queued first by increasing ask prices and second by earlier arrival times.

- Use of Quote Accepting Policy

The policy is used to decide whether a market offer should be accepted or rejected. It relies on the specified orderbooks and may follow additional rules, such as the one that only bids and asks that improve on themselves are accepted in the market (Vytelingum et al. (2010)).

- Market Clearing

The market clears continuously and every time the state of the orderbooks changes (i.e. by new or an improved offer) it searches for a new best match. Continuous trading, as used by Vytelingum et al. (2010), is associated with the pay-as-bid (discriminatory) market clearing principle.

- Security mechanism that defines the transmission line cost for each transaction

More specifically, the security mechanism determines whether a match between a bid and an ask is feasible, and if so what is the associated transmission cost. For the purpose the secure quantity that the network between two nodes with matched bid and ask can handle is computed. The calculation is based on the capacity constraints and the transmission line charges.

A schematic illustration of M1 is presented in Figure 26 below.

Figure 26: The local electricity market according in M1 (based on the study of Vytelingum et al. (2010)). A day-ahead trading period.

- **The local flexibility market**

The balancing mechanism used in Vytelingum's study to settle prices for extra demand and supply intraday in real time represents a solution for the local flexibility market. Clearly, balancing electricity demand and supply in real time is crucial for maintaining system stability. As the electricity market operates for a day-ahead trading period, the unmatched bids and asks from agents who are willing to trade in real-time are visible in the orderbooks. To keep the system in balance the following market-order bids and asks are considered:

b^{f+} Additional demand required by a buyer, to cover actual consumption that exceeds what has been agreed on within the day ahead trading.

b^{f-} The extra power that the buyer has demanded but is unable to consume.

s^{f-} The extra power that the seller is unable to supply.

s^{f+} Flexibility (extra power) that local market participants are willing to provide

The above presented offers are positioned at the top of the previously discussed bid and ask orderbooks. In particular, b^{f+} and s^{f-} are being priced at the Dynamic Locational Marginal Price for buyers ($DLMP^b$) at the respective node. This price represents the lowest cost of buying one more unit of power from the unmatched sellers plus the transmission cost as assigned by the security mechanism. s^{f-} is priced at the Dynamic Locational Marginal Price for sellers ($DLMP^s$) that is computed similarly to the $DLMP^b$ but considers the highest price of selling one unit of power to the unmatched buyers. In addition, s^{f+} is added to present the flexibility that local market participants are willing to provide, for example, based on some predefined contractual arrangement with the SESP.

A schematic proposal for the local flexibility market in M1 is presented in Figure 27.

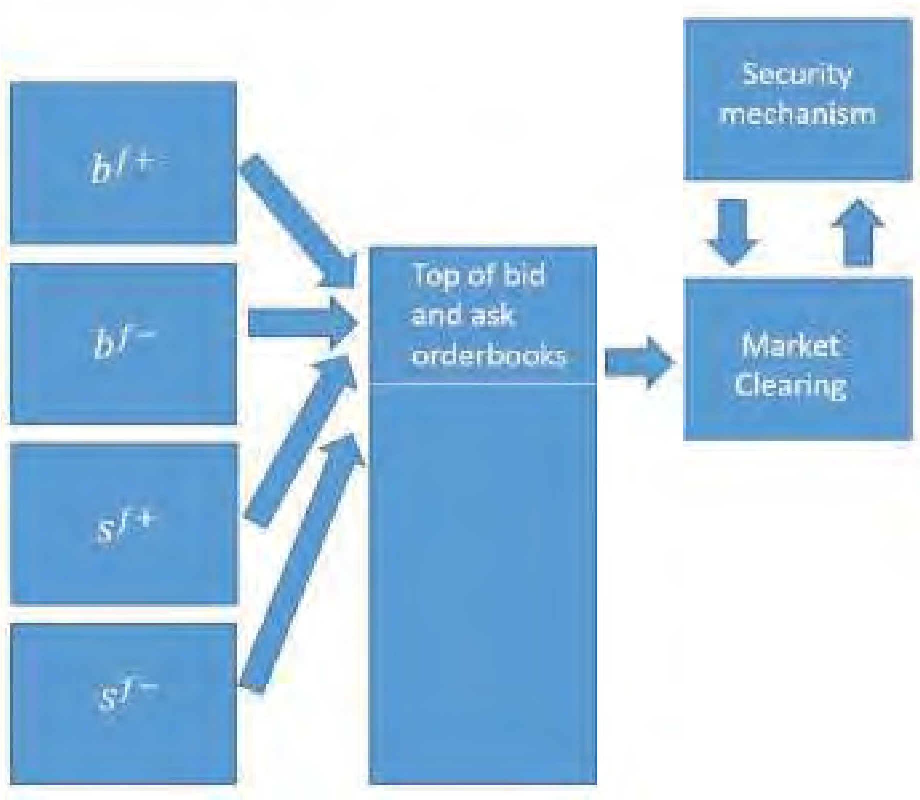

Figure 27: Trade at the local flexibility market according to M1.

- **Other services market**

When it comes to the other services market, the CDA proposed by Vytelingum et al. (2010) with bid and ask orderbooks is hardly applicable. The other services market would be more realistically based on a longer term contractual agreements between end-users interested in the service and the service provider (e.g., the SESP, an independent service provider, or sub-contractors that operate under the premises of the SESP).

9.2 Model 2

Model 2 (M2) describes the local energy market concept presented by Ilic et al. (2012). The energy trading market is referred to as the NOBEL market (Neighbourhood oriented brokerage electricity and monitoring system), that operates in the Spanish city of Alignet in 2012. The NOBEL market is involved in energy trading only and is not concerned with the flexibility market or other services market.

- **Market Design**

The NOBEL market is based on the stock exchange model with the difference that the trading periods are discrete fixed sized time slots throughout the day. The order book and transaction price are made public. The time slots are defined as $x \in X$, where X is the set of all timeslots where trading can be realized. Trading periods are discrete fixed-sized time timeslots of same length δ. Every participant places a market order $o_i^x, i \in N$, in the order book O^x at each time slot. To facilitate meaningful interactions in the market, both consumers and prosumers should be capable of predicting their energy demand/supply for a timeslot. Orders once placed can still be adjusted when the time slot is open so that prediction deviations can be accounted for. For each o, the type (buy/sell) is specified for the number of units (volume of energy) and the price p per unit that the participant is willing to trade for.

In the simplest case, the participant can observe the top of each order book to get an estimate of the best buy and best sell orders and use these as a reference point for positioning its initial quotes. If a buy order has price p_{buy} and sell order has price p_{sell}, a transaction (order matching) will only occur if $p_{buy} \geq p_{sell}$. The matching process will be repeated every time a new order is received. An order o_i^x may represent only a portion of the participant's demand/supply to be met locally and hence may only partially match with multiple orders from the time slot's set of orders O^x. Since an order may not be fully executed, it possibly stays in the order book, but only with the remaining unmatched quantity. The matching process is repeated every time an order is inserted or updated.

Matching is based on the first come first serve (FCFS) policy. Every newly received order, update or cancellation, will be sequentially executed. Therefore, participants placing orders earlier in the trading time slot will have advantage over others placing their orders after them. Every matched order in the trading period for a time slot can be considered as the contracted good. This contract is made between participants of the matched orders executed by the matching algorithm.

- **Market Implementation**

1. Order configuration – Different order configurations are available for the participants, where traders can express specific energy. The order configurations are composed of two behaviors as shown in the following table.

Table 4: Order configurations available for market participants in M2

Fully Match \ Immediate Match	YES	NO
YES	Standard	Immediate Or Cancel (IOC)
NO	All Or None (AON)	Fill Or Kill

The first dimension, specifies whether units of an order can be partially matched, or if they must be fully matched. "Fully match" indicates that a participant wants all or nothing. The second dimension specifies if an order has to be matched immediately. If immediate match is required, possible matching is executed while the unmatched part of the order is automatically cancelled. Matching limitations of this dimension are the trading price and availability of the trading commodity. With these four order configurations, participants should be able to express their internal processes, or trading strategies.

2. Architecture – The market architecture (previously presented in Table 3 in Section 5.2) is shown in Figure 28. A market participant submits an order to the market through the market communications manager (who performs the necessary security checks). Firstly, the order validity check is made within the verification module. It checks if an order complies with all market rules, that is, price limitations, order configuration, time slot validity, etc. The market kernel module is responsible for managing the life cycle of the time slots, their order books, and the order matching process. Once a new order comes in, it is passed to the matching algorithm, along with the order book for the order's time slot. If there is a matching executed, the state of an order changes, and the market output manager is notified of the transaction. Since an order might not match as soon as it arrives, the output of the market is handled asynchronously. Market participants and

other tools (e.g. an external analytics service) can subscribe to this module and receive the produced market notifications. Some of the parameters of the market can be changed at runtime by updating the verification rules module.

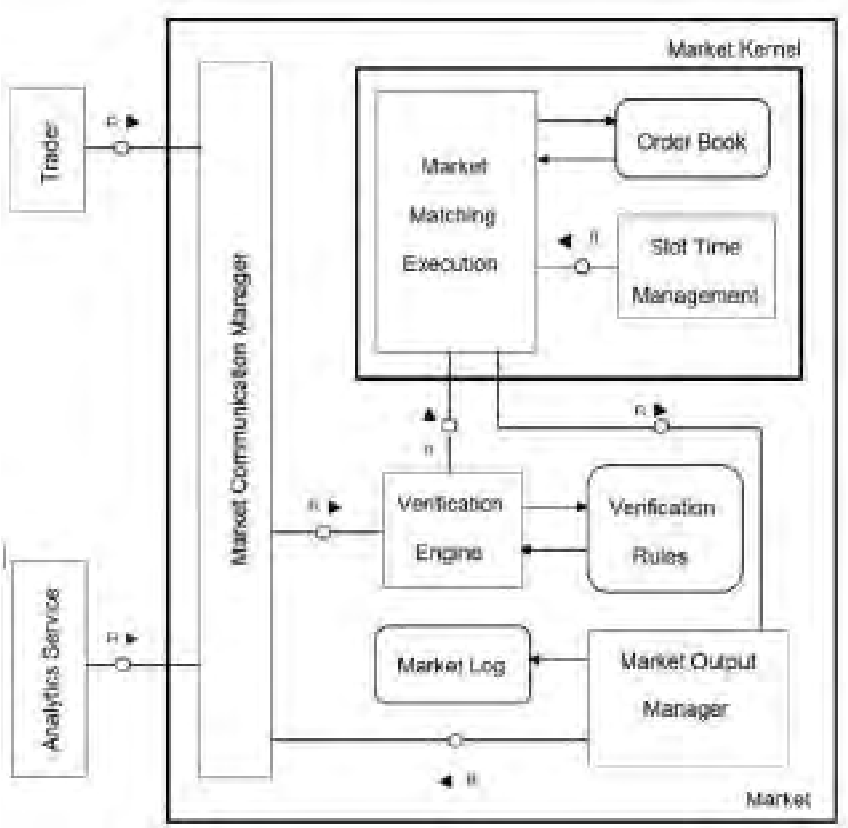

Figure 28: Market architecture in M2 (Ilic et al. 2012)

The matching algorithm must handle different cases when a particular order type is being matched with another order type. In the case where an order requires immediate matching, the trigger order passed to the process is used. If, after a run of the matching algorithm, this order is not fully executed, all the remaining quantity is cancelled. When one or two orders which need full matching match, the availability of all quantity has to be checked. To reduce the central processing unit cycles of the matching process, all orders are ordered according to their price and their type (buy or sell). Their quantities are added until the required quantity is reached. If the quantity is achieved and the price limit is not breached, the entire quantity needed by the order is available at or below the required price; hence a trade takes place. However if the incoming order only required partial matching and the top order required full matching, this process also needs to be run again for that particular order, as there can be previous orders with which the total quantity can produce a match. The matching algorithm may not let a full matching order block trading. For instance, if the cheapest sell order required fully matching, and there is no combination of buy orders which can fulfil the sell order, the market should not wait until the sell order can be processed before processing the other sell orders. Therefore, in this case, the top order is ignored, and matching is attempted with the remainder of the orders.

The proposed market has been implemented in Java SE v6 as a simulator. ZI trading agents are used to evaluate the proposed market. A ZI has no memory, and no guiding trading strategy, and simply bids to the market using random (within a user-specified limit) pricing. Since the behavior of ZI can help reach a high level of order matching, the equilibria of the market can be found. The aim of simulations was not to apply a trading strategy (e.g. to maximize the profit), but to try to understand the outcome of the market model given its rules.

9.3 Model 3

9.3.1 Basic model

Model 3 (M3) is a derivative of common security trading mechanisms and real-time control. It is inspired by work previously carried out by (Carella 2014, Lorenz 2008, Bremdal 2015). The trade is split into three stages: A marketplace for exchange of futures and creation of forward contracts, an intraday market and a real-time balancing market. The conceptual model is shown in Figure 29.

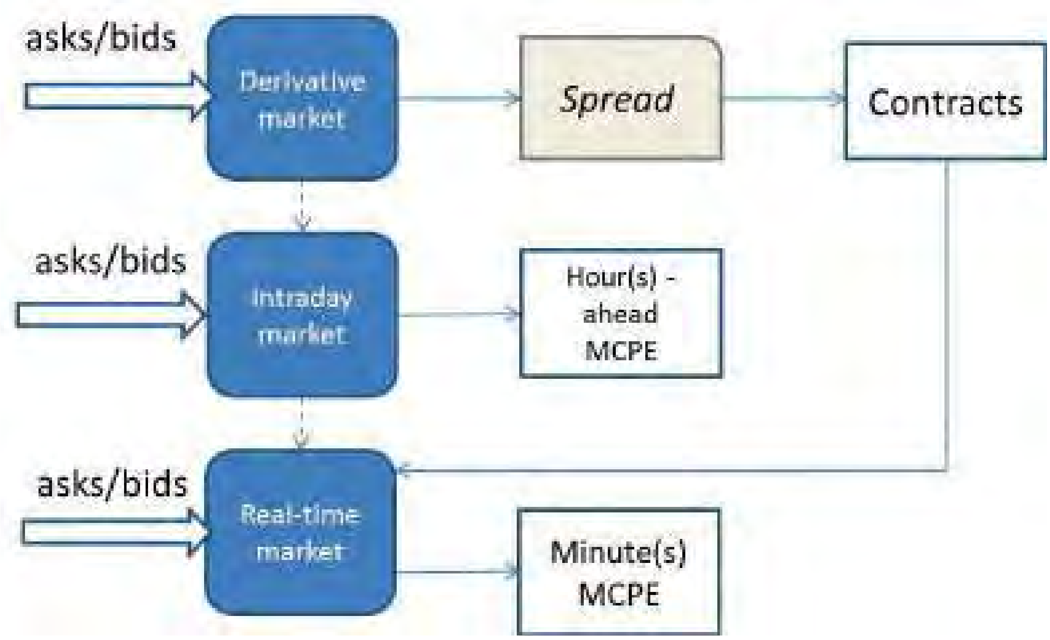

Figure 29: A three stage market concept with emphasis on futures and forwards

The bulk of the trade is handled as a financial matter. The idea is that use of intermittent energy and partially random irregularities that cause capacity challenges that need to be contained not only physically, but also financially. Risks must be reduced or sold out. Risks are related to integration of local renewables, local congestion management, mediocre predictability of future energy generation associated with the obligations that a well-functioning market expects. Poor forecasting or failure to comply with obligations defined in future agreements constitute a challenge. This can produce an unbound surplus which has not been committed in the derivative market. The deviation must be dealt with as the time for delivery approaches and can be carried in two stages: in an intraday market and in a real-time (e.g., 15-minute) market.

9.3.2 The derivative market

The established markets accommodate different forms of security trading. Both forwards, futures and other forms of risk hedging have since long been introduced. This model places strong emphasis on risk containment services too, in combination with the use of flexibility and energy trading. The approach makes several assumptions. The principal one includes the DSOs' desire to reduce peak loads and manage voltage in parts of the grid during peak hours. Another basic assumption is that consumers would like stable, affordable prices. Yet, they would be inclined to buy local, green energy as long as there is little extra cost involved. Consumers are also believed to renounce the most elastic fraction of their consumption for a price benefit. Prosumers and suppliers, on the other hand, are assumed to emphasize the best possible pay-off for their investment, but also recognition for contributing to a "greener world". It is further assumed that prosumers and regular suppliers may be inclined to look for ways to reduce the risk for penalties when actual delivery to the market deviates from the obligation made. This concern is shared by aggregators at large. In central markets the cost of failures to deliver on time is largely shared among all subscribers in a grid. This may not be so in the future. A local market is more vulnerable and this issue must be resolved in a more justified way.

The concept targeted resolves major issues through the use of securities and with an entity like the SESP as a kind of market maker. The iPower model (Zhang et al. 2013) suggests an up-front agreement to secure future activations of flexibility. In practice the proposed flexibility market suggests the use of forward options to resolve the challenges the DSO might anticipate. It is partly a take-and-pay contract as the fixed fee will never be remunerated even if the activation of flexibility is not triggered during the contract period.

The need for up-front contracts is also linked to a technical necessity. Those subscribers wishing to take part need to be equipped with the proper equipment for demand response or supply control. One problem with this approach is that the DSO operates as a monopoly and can to a great extent determine the price. However, the need for sufficient flexibility is also a concern shared by others. Prosumers, suppliers and aggregators could hedge their interests through the same mechanisms. In a market of limited size the flexibility trade could be subject to efficiency issues. Consequently, one or more market-makers could be introduced. A typical market maker could be a storage service provider, but under various regulatory regimes the SESP could also take this role. A volatile market is likely to encourage all parties to seek increased stability. Trade in futures to secure stable prices over a longer period of time is a common instrument. This can be combined with the type of security that the DSO needs. However, someone must be willing to take the risk. This is where the community and the SESP come into play.

Another risk element for local trade is the unconstrained access to a central market. This creates a significant influence on the local market. If taxation and grid tariffs for locally generated energy are disregarded and commissions for trade in the central market are kept low the central spot-price will influence the local trade. Consequently, the local market and the pool manager need to beat the central market so that prosumers and consumers maintain a local focus. Organizing the community as a kind of shopping club is one way to deal with this. Another is through proper risk management.

The security model proposes a future market with fixed trade intervals, e.g., day intervals. Framework deals with the DSO and other parties wanting to secure future flexibility are worked out. There can be several flexibility products (see examples in Table 5). Quotes for each can be made in the form of both a fixed fee and an activation fee.

Table 5: Different services to assure operations and planned exchanges of energy

Service	**Stake-holder(s)**	**Fixed fee**	**Activation fee**	**Fixed volume per activation**	**Max number of activations per period**	**Max duration per activation**
Scheduled power cuts	DSO	yes	yes	yes	yes	yes
Instant power cuts	DSO	yes	yes	possible	yes	yes
Power reserve	DSO	yes	yes	yes	yes	yes

Guaranteed generation ceiling	DSO	yes	yes	yes	yes	yes
Voltage support	DSO	yes	yes	possible	yes	possible
Reactive support	DSO	yes	yes	possible	yes	possible
Negative off-plan supply (normal operations)	Prosumer, supplier, aggregator	yes	yes	no	yes	no
Negative off-plan supply (irregular or failed operations)	Prosumer, supplier, aggregator	yes	possible	no	possible	no
Positive off-plan supply	Prosumer, supplier, aggregator	yes	yes	no	yes	no
Peak hour elimination	Consumer	yes	yes	possible	yes	yes

Trade of securities can follow the same pattern as in the financial market using a CDA. This will produce a spread that would eventually lead to a settlement for a price. Yet, the volume of the assets being traded within a community may not be sufficient to produce the desired liquidity. Instead, a form of Dutch auction for each product offered can be applied. The lowest quote for each flexibility product will be ranked highest. To satisfy the needs of a DSO a single supplier may not be sufficient. Hence, the need for splitting up the request in lesser parts would be needed. This can be done by the SESP or the DSO itself. The latter lends itself well to a double auction. A double quote is required for all the products being auctioned, one for the fixed part and one for the activation. A pre-declared part of the fixed fee offered will be earmarked community purposes. The rest will be part of the compensation that each participant will receive. The dividend that will be credited to the community is to be accumulated and used for two purposes: to facilitate the trade purpose (e.g., buy-back) and to generate bonuses for engaged and loyal traders.

Quotes volunteered can be provided for a specific set of hours, a particular day or a period. This produces a flexibility calendar (Figure 30), with a tentative flexibility requirement for each hour or day. As some activation to be driven by circumstance wildcards in the calendar may exist, such wildcards are likely to generate the highest quotes. They can be modelled with a likelihood function. Activations are only options and can be traded bilaterally or in a secondary pool. In the same market energy futures can also be traded. The SESP and others can offer a fixed price for both consumers and local prosumers for a specified period T.

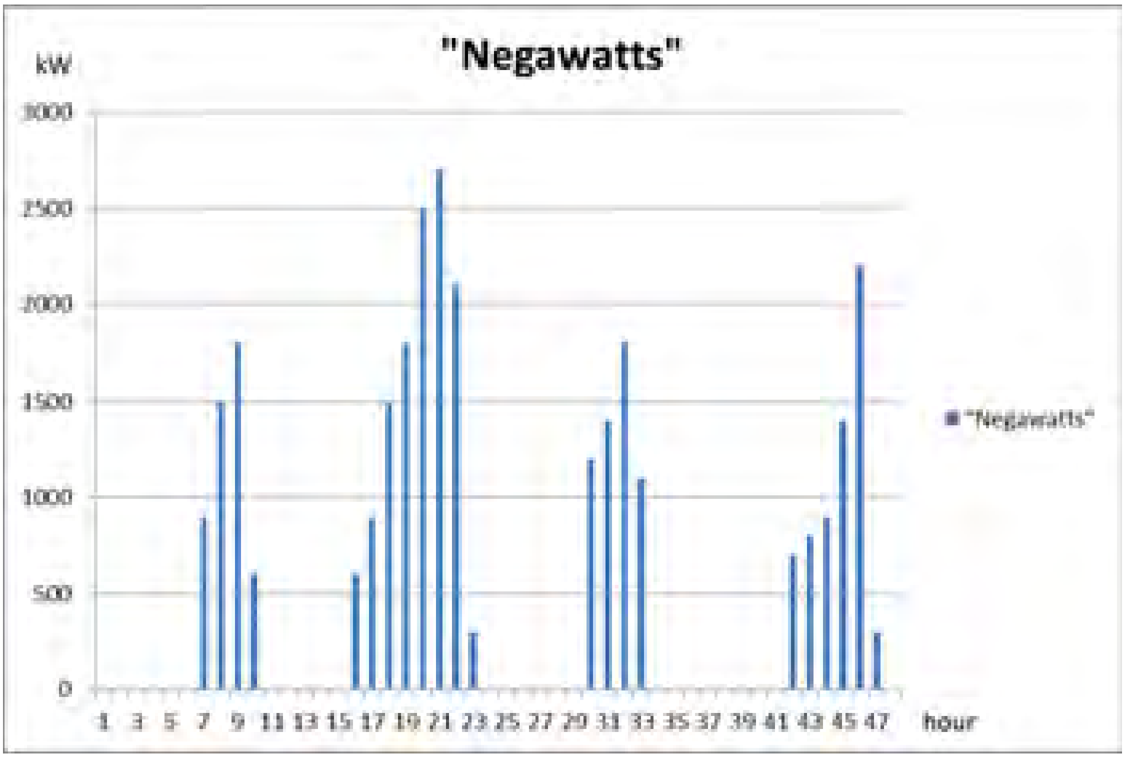

Figure 30: An aggregated flexibility calendar

Since the result of the flexibility auction is shared prior to the sale of energy futures, bidders and askers will take this information into account together with a price prognosis for the central market. Although the implications of this will vary for all traders, we must assume that the information is not arbitrarily applied and that all traders are reasonably well informed.

9.3.3 The intraday market

The intraday market can trade surplus energy not tied up in futures. It will also allow non-activated energy and energy operations earmarked for flexibility services that day to be traded. Moreover it is the arena for replacing committed extra energy or reduced demand that is forfeited due to technical or other problems. A non-continuous double auction could handle this. If prognoses are accurate and commitments are held the intraday market will play a minor role or become possibly obsolete. Smaller deviations, minor errors and rapid technical responses can be handled close to real-time.

9.3.4 The real-time market

In this market trade goes on continuously as the need arises. The idea is to detect and compensate for issues that may arise within the hour. This need can be driven by pre-defined activation plans determined in the derivative market or as a need for instant adjustments due to congestions, sudden failures or similar. In cases of pre-specified activations the trade process is reduced to pure remuneration based on predefined prices. But participants that have not been active in the derivative market can use this to trade compensating measures there and then. This naturally poses a risk for not achieving an affordable compensation and the idea is to drive as many as possible into the derivative market. High-frequency compensations would be preferred, but 1-minute, 5-minute or even 15-minute trading could work.

The compensation could be well managed automatically using basic control or fuzzy control engineering accommodated in agents. The simplest form of agents would be the ZI agent type based on the PID principle (see *Figure* 31).

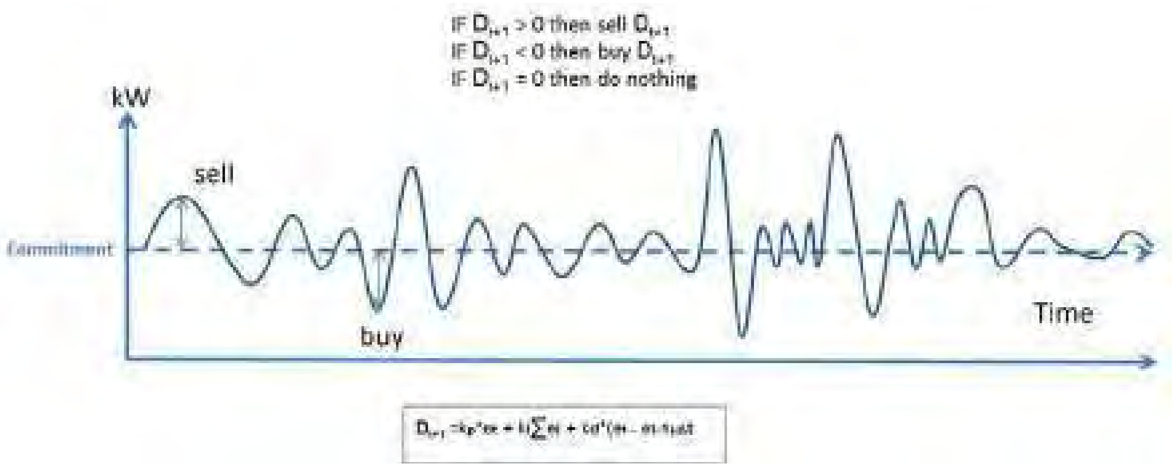

Figure 31: A PID approach used to fulfill a commitment

The factors Kp, Ki and Kd can be associated with a price and compensation tuned accordingly. In fact each element in the equation can be associated with a specific, predefined set of services, each with a specific price. Hence Kp*et could be managed by a battery or fly-wheel type of storage service, the integral part could be managed by demand response and repair services. The derivative part could be managed by a third storage service.

9.4 Model 4

Model 4 (M4) focuses on the flexibility market and tightly follows the concept described by Zhang et al. (2013) where the specific application within the iPower project is presented. Consumers, producers and prosumers who are able to offer flexible loads are aggregated by the SESP. The SESP trades the aggregated flexibility on the local flexibility market. In the particular case of Zhang et al. (2013) the trade goes via a flexibility clearing house where contracts are regulated and ex post financial settlement is carried. Yet, as in EMPOWER's market design (D6.1) the SESP has also been defined as a legal entity that is to ensure the efficient trade of energy and energy related services, it should be possible for the SESP to be both an aggregator and a responsible body for organizing the trade with flexibility services. Thus, the operation of the flexibility clearing house is seen as integrated within the functionalities provided by the SESP. Figure 32 below presents the simplified structure of the local flexibility market.

Figure 32: The local flexibility market according to M4

Based on previous data and network planning the DSO (buyer of flexibility: b^f) submits to the SESP (aggregator and seller of flexibility: s^f) its demand for flexibility. For the DSO flexibility represents a tool to support congestion management through treatment of overload and through voltage support. Peak load can be decreased in both predictable and in urgent situations, there might be set boundaries on the total load used by the local community, or there can be requirements for keeping within certain capacity limits/reducing peak load when reserve power is needed.

The demanded quantities could be specified by different time characteristics and a deadline for submission of bids by the SESP is set. On the basis of the submitted asks and bids, offers are matched and contractual agreements are made.

Zhang et al. (2013) propose a longer time span from the time the auction takes place to the actual delivery. In particular, a year-ahead planning is considered and the aggregator may have to go through a testing process as the time of actual delivery gets closer. However, M4 considers the possibility that flexibility is traded also on a shorter time intervals. The use of a testing process is therefore less probable and could be substituted by certain penalties for the SESP when it failed to deliver the contracted flexibility.

Alternatively, the scale of flexibility resources aggregated by the SESP could be so large that the there is always a margin to ensure that the SESP activates flexibility according to the agreements made, even when some of the distributed loads fail.

M4 describes the possible trade only within the flexibility services part of the local market while the possible thorough market design should consider combining the M4 concept with already proposed in the preceding models local market concepts, so that the energy and other services part of the local market are accounted for.

10 Conclusive discussion

We have explored the concept of trading in local markets and addressed underlying theories and practical solutions. Although comprehensive the report is not exhaustive. The approaches to local market design and trade reported in the literature vary considerably. The use of MAS and other ICT provides opportunities that have few references in the traditional wholesale markets for energy. We have therefore limited the scope of our study to such models and deliberately avoided a more extensive analysis of the classic power markets. This decision was supported by the fact that we have also introduced more radical concepts such as a commercial community that will harbour the trade. Moreover, we have tried to be faithful to the goal of integrating distributed renewable generation effectively and concentrated on the associated topics. Similarly, we have stressed aspects that relate to trade in energy related services, in particular services that may unleash flexibility in the distribution net. We are aware that some issues need to be further developed in task T6.3 that is ongoing. An example is how and who will pay for the technical losses in the grid. This and other points of discussion will be treated there in light of the specific design created. Here definite references have been made to the elements introduced in the EMPOWER project that make it distinct:

- Market design
- Prosumers
- Communities
- Trading agents
- Trading concepts for local markets

10.1 About the overall market design

The overall market design for EMPOWER was defined in task T6.1 and described in deliverable D6.1. From the deliberation provided here no evidence suggests that the market concept cannot support the type of trading ideas discussed. On the contrary, the need for a flexible and robust market concept should be reinforced. The SESP may take on additional roles, such as a market maker in addition to offer a trading arena, being a type of broker and a clearing agent. The extended mix offers some clear advantages similar to those found with well-established commercial communities such as shopping clubs. However, different regulatory regimes may not approve this. The need for splitting the roles assigned to the SESP may thus be required. However, it is preferable if those roles are kept within the sphere of the local community. The need for connectivity to other markets has not been weakened. Limitation in terms of both storage capacity and generation are likely to require access to external sources to cover the neighbourhood demand. However, active trading by local prosumers offers more flexibility. This can yield advantages that have been pointed out. Peak hour trade may be a particular form of local trade to be seriously considered.

10.2 Prosumers' role

Local prosumers operating facilities for generation of renewable energy occupy a central place in the EMPOWER concept. In order to illustrate the potential opportunities and caveats that must be addressed we have undertaken an empirical analysis with data gathered from one of the intended pilot sites. From this we have pointed out how prosumers can match and balance the needs of their neighbours.

10.3 Increased emphasis on trade in energy related securities

Our analysis and follow-up discussion elevates the role of trade in derivatives. Once engaged in trade prosumers and small-scale suppliers, operating distributed energy sources based on solar power or wind, are likely to seek some kind of protection or financial support. In addition to measures that support or improve life-style requirements, security may be the most important criteria emphasized by community members, especially in low price markets. Non-professional traders are involved, and despite an ability to deliver surplus they are first and foremost consumers pre-occupied with other tasks than energy related trade. This is, of course, why the use of trading agents is so important too. The need for security depends on how balancing needs and non-conformance issues should be dealt with. The latter is connected to how well the parties are able to fulfil their obligations once a trade commitment is made. This pertains to both up-front scheduling and forecasting. However, a risk still exists. This liability can be reduced by increasing the trade frequency in the regular spot market as pointed out in our discussion on the financial market. A separate and even complimentary way is to hedge the risk by means of futures and forwards. This means that consumers and prosumers within the same community can settle how they wish to deal with future deliveries. Contracts, where one party buys surplus energy while the other buys back flexibility in the form of demand response, present a solution that can be established. The price agreed upon thus reflects both the cost of energy and the possible compensation for unstable supply. However, other parties may pursue similar ends. The local DSO is the most prominent case. Here we have looked to former initiatives that aim to establish a flexibility market. This flexibility market is introduced to help DSOs reduce congestion issues, decrease loads and maintain voltage. The idea is to determine, by means of auctions or direct negotiations, a set of contracts for different flexibility services to be delivered later. Such contracts typically apply a two-price system, one for being prepared and one for activation. In fact the type of contracts described for this flexibility market take the form of forwards. The SESP or others can negotiate a bilateral agreement with the DSO and turn around, split the deal established into secondary contracts and sell these to community members.

10.4 Utility orientation rather than kWh focus

A couple of trading models presented show how forwards and futures can create a look-ahead and therefore increased predictability that are likely to be embraced by many. This look-ahead may include concerns related to energy exchange, the need for flexibility and other services that can assure local power balance and a secure, local supply. From this arise two issues that have been discussed. One relates to the composite needs involved. The other is concerned with the break-down of the total cost involved. The first suggests a departure from mere trade in kilowatt hours. Contracts highlighting a standard utility scheme seem more appropriate. We have discussed the theory behind this. The other underpins the type of value focus that was first introduced in D6.1. Beyond all, it points to a trading process where equilibrium cannot be pursued on energy needs and price per kWh alone. Rather a more general form of equilibrium, if possible, should be sought through the EMPOWER trading process.

10.5 Service providers that offer risk reduction

If neither the consumer nor the prosumer is willing to take any risk someone else should offer this. The SESP has already been mentioned. However, this is definitely a type of service the community should seek to include. Consequently, parties that offer this should be invited in, preferably on terms comparable to that of shopping clubs that we have described and in accordance with the market design described in D6.1 and the business concepts offered in D2.1.

10.6 Energy storage services offer security

Besides traditional financial security sales organized in this manner, energy storage should be invited in. Similar objectives could be achieved. Energy buffers will enable prosumers and others in need for future flexibility to buy storage space or storage management services, giving them the possibility to deposit positive surplus or retrieve compensation for deficits. Energy storage rent offers a service that can be traded long before activation, thus creating the necessary predictability and risk sharing. The motivation behind all of this is to encourage generation of local energy and exchange it close to the terminal points in the distribution net. By reducing the risk and increasing the incentives concurrently at the supply and demand success is more likely.

10.7 SESP and the need for capital funds

If the SESP actively enters such a market as market-maker capital funds are needed. We have argued that there is a need for a membership fee to build funds of this kind. But other capital sources are likely to be required too. One such source could be subscription fees for stand-by flexibility that the SESP negotiates with external parties such as the local DSO. With sufficient capital resources the SESP could offer buy-back contracts too. This suggests a promising alternative to demand response in order to manage congestions on behalf of the local DSO.

10.8 Trade considerations should encompass typical externalities

An integrated market of the kind proposed must try to encompass cost and income elements that today are treated as mere externalities. The grid tariff is one case in point that has been discussed. Emerging tariffs tend to encourage self-consumption. The introduction of peak power tariffs reinforces this. As shown, tariffs may have a profound impact on the market position of the prosumer as well as the consumer. The price currently settled in spot markets may therefore produce a demand and supply surplus that is suboptimal or even misguiding – a case that must be avoided for local trade. This issue further demotes sole focus on partial equilibrium.

We have argued that grid tariffs should honour energy balance within the neighbourhood. Shared self-consumption whereby locally produced energy can be exchanged to meet local demand should be encouraged. Tariffs that distinguish between energy exchanges with “a territorial relationship” from other exchanges represent a step in a direction that we think should be pursued on a general scale. The price established, in the form of one trade or another, will reflect all the composite elements addressed here. The likelihood that local markets will operate with different prices is imminent. This difference is likely to express inconsistencies between districts and expose infrastructural deficiencies. It will also display the cost ratio between short-distance supply and long-distance sourcing better than today. This could in turn lead to initiatives that improve the total social welfare.

10.9 Adoption of shopping club principles

The community concept was inspired by the energy cooperatives spreading across Europe, and which represent a new addition to the string of citizen oriented cooperations throughout history to improve conditions of living. We have compared communities and energy cooperatives with established commercial institutions that are turfed on some kind of collaboration. A few things can be drawn from this. As a shopping club the community can offer a distinct market for services and products. The fact that the community may rally for certain bargains and essentially rule out middle-men should cater for rebates. This in turn will make it attractive to join and remain a member. Activity, loyalty and engagement will be honoured. A good reputation should be formally and financially recognized by the community itself. Moreover it paves the way for issuing membership fees that can help to grow funds. In this discourse we have discussed some important implications of the topic.

10.10 Coalitions versus self-interest

First of all, the trade model settled on needs to depart from the idea of purely self-interested traders. The difference between cooperative agents and self-interested ones is explained. What is more important is that this will mark a divide between former initiatives presented in the literature and EMPOWER. The state-of-the art that has been discussed assumes, explicitly or implicitly, that trading agents will seek profit maximization under policies that are purely self-interest driven. EMPOWER agents should adopt a mixed strategy where trading agents should be able to maintain self-interest and the common good of the community and its members. One way to deal with this is to introduce coalition thinking as the basis for trade. By working through the community self-interest may be attained. Recognition systems and reward mechanisms will therefore be important.

10.11 Size of local markets matters

The size of local markets may vary. Nevertheless, the number of potential trading participants and community members may be limited. This could potentially hurt all forms of trade. The business concept proposed in D2.1 suggests that the SESP role and its technical and commercial inventory could be part of a franchise system. This is one way to attract more suppliers of general services and associated products. Discounts could further be increased as members of different communities are exposed to the same offers. This could again raise funds for the SESP which in turn could use this actively to facilitate trade and market liquidity. But a caveat must be observed. If the dominance of the SESP as a market maker or as an active participant in other ways becomes too big the SESP will assume a type of aggregator function. Besides, if the perceived value related to the service and product/app part of the market is much higher than the energy itself, traders may grow indifferent to energy prices. This represents an inherent danger in low price regions such as parts of the Nordic countries. A way to deal with this is to create a very tight connection between the three different parts of the EMPOWER market. A synthesis of the selected models promises a way to resolve this.

10.12 Utility oriented trading agents

Different forms of trading agents have been described. It is shown how such agents are applied by other authors embarking on a similar mission to our own. We have also emphasized the importance of such trading agents in the security and stock market. These are not zero-intelligence agents, but sophisticated information processors that exploit the power of modern computers. A close-up look on the role that zero-intelligence trading agents have has also been provided. Based on our investigation of pertinent trading concepts, both academic and commercial, and the needs of the EMPOWER market concept, a theoretical foundation has been reconnoitred. The most important aspects in this respect relate to trading policies and what equilibrium model should serve as reference for further work. As pointed out in D6.1, the use of trading agents has been introduced to leverage the role of non-professional traders. Equally distributed information is essential for market efficiency and fair distribution of market power. The theoretical foundations associated with trading agents operating within the cooperative environment that the community offers have also been treated. As already mentioned pure self-interest should be sacrificed for shared community benefits, which again can be applied to lubricate the local trading process. Thus, new possibilities, also with respect to congestion management and how to integrate this within the basic trade process itself, are provided. We further argue that utility oriented agents can handle this and thereby enable a more holistic approach to the trade and cater for settlements that seek general equilibrium. However, we see formulation of a proper utility function as a challenge.

A system based on ZI agents may not be a goal in its own, although it promises uncomplicated solutions for both market and users. ZI agents are more likely to play an important role in EMPOWER to determine the soundness of the market.

10.13 EMPOWER seeks an approach that differs from previous efforts

Previous work on local/micro-markets has applied different approaches. Most of them have in common that they place absolute emphasis on energy trade alone. The few instances that treat congestion issues and flexibility manage these very much as a post-trade effort in the classical way. Partial equilibrium is sought. The EMPOWER approach seeks a solution along a different direction. In our opinion the operational basis that is offered by ICT and described partly in D3.2 can greatly revise this and support integrated trade.

10.14 Non-continuous trade versus continuous trade

An issue that has been much debated during task T6.2 is the application of continuous trade versus non-continuous trade. The former can be easily maintained by the type of trading automation that will be available. The majority of former efforts has also adopted CDA principles. There are caveats associated with this, especially when energy exchange and congestion management are handled in sequence. A basic critique is that this will introduce measures that tend to penalize those who may not contribute to the congestion. Rather, congestion management should be handled through engaging incentives, allowing those who wish and have the capability to alleviate the congesting situation to make a profit. A non-continuous practice has traditionally been a better option for the central market as volumes for the day-ahead market are settled before bottleneck considerations are made. However, previous efforts seek to resolve this by means of buy-back procedures. The way demand response is offered today represents a form of buy-back that will be considered by EMPOWER. This will leave the SESP or a party especially assigned by the community, in the position of the TSO. The SESP's position and responsibility should be alleviated by means of collaborative agents and resource management based on game theory.

10.15 Several trade characteristics must be honoured

In this discourse we have further tried to elicit other trade characteristics needed for our design specification effort in task T6.3. These characteristics have been extracted from the models studied and represent elements that we consider to carry particular weight. The prototypes that we have shortlisted and described will serve a similar purpose and constitute important references for both specification and testing of the final concept that will precipitate from WP6.

10.16 Trading frequency – still an issue

One caution should be made that could have some impact on further work. Neither the literature study carried out nor preliminary analyses performed have produced a consistent answer to what trading frequencies should be maintained in EMPOWER. Propositions range from 5 minutes to 15 minute intervals. Experiences from trades in the stock market suggest that higher frequency trades could be beneficial in several ways. One of the selected prototype models in the last section supports this philosophy. The ICT that will be made available for the market cloud will be able to support HFT, too. The need for accurate forecasting will be reduced while the need for tactical dispositions and policy development is likely to increase. The technology needed to execute control of hardware, signal exchange and metering may, however, pose a constraint, at least for a durable period as increased on/off operations may accelerate mechanical wear and tear. Having stated this, work so far has shown that if energy sales are treated purely as forwards and futures, only demand response will be required in the short run. The flexibility part that needs to satisfy market obligations may require compensating measures only every 5 minutes. Flexibility services directed towards the DSO, much in the way explained for iPower, may in general extend across hours and even months. Managing local voltage control and flexibility to handle reactive power may again require higher frequencies of real-time trade if contracts for these services are not treated as forwards.

This suggests that the design produced should leave room for further experimentation and with the experimentation being preferably done in the form of simulations. But we also see a need for some latitude once the concept is deployed at the different pilot sites.

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