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Community Energy System

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Peer to peer energy trading allows surpluses from distributed energy sources to be traded among prosumers and consumers in a community. This can result in lower energy prices and a higher self-sufficiency. How such a peer to peer network takes shape and which advantages it brings, is depending how large such a community is and how much energy can be stored.
A case of 20 detached houses with a household size of 2.15 persons has been studied. There has been looked at three scenarios, a gas and electricity consuming house, an all-electric house (divided into 3 subscenarios with different heat pumps) and a future scenario where all the all-electric scenarios are reconsidered with technical advancement in mind. Each scenario has been given solar panels in order to produce renewable energy. This means that storage is required to prevent surpluses in electricity generation going to waste. The capacity of this storage system is scenario dependent because of the difference in energy consumption. Hence, the influence of a peer to peer network is different in each scenario.
A peer to peer network of this size was found to be least favourable for a gas and electricity consuming household and most favourable for a present-day all-electric scenario.

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1 Introduction

The world's energy consumption keeps on increasing. To be able to supply the energy demanded, the amount of energy produced needs to increase. Present day electricity is for 80% being generated using fossil fuels. Around 50% of this has been coming from nationally produced gas [1]. Not only do the fossil produce a lot of greenhouse gases, the gas extraction from the Groninger fields have resulted in multiple earthquakes in the last few years. These earthquakes sometimes even made homes uninhabitable. To prevent the earthquakes from getting worse, the Groninger gas field is being shut down. This means that the national production of gas will drop below the demand and gas will need to imported. Importing gas will cost the government money, because not only does the import bring additional costs, there is less gas to export, so the states income will decrease as well. The increasing costs might however bring something good. The Dutch government wants to reduce the emission of greenhouse gases by 49% in 2030 and by 95% in 2050 with respect to the emissions in 1990 [2]. If the costs for using gas increase, investments in renewable energy might be made quicker and make it easier to reach the targets of greenhouse emission reduction.

This is what is happening. The capacity of renewable energy sources is increasing rapidly. The solar panel capacity has increased by more than 50% in 2018 compared to 2017 [3]. Together with the growing capacity of wind turbines, the share of renewable electricity in the total Dutch electricity consumption has increased from 14% in 2017 to 15% in 2018 [4]. In 2016, it was planned that in 2023 16% of the total energy is produced via sustainable sources. The 16% is almost reached already. However, in 2015, the goal was to have a share of renewable produced energy of 20% in 2020. This shows how difficult it is to predict future energy productions.

Reaching the CO_2 reduction goals means that changes in all sectors in society (households, buildings, industry, transport and agriculture) have to be made. To reduce the emission from each sector, research for each individual sector has to be done. Agriculture, households and industry all have a very different consumption behaviour. Agriculture has its transport part where changes are needed, but also in the fertilizers used, which are made from fossil fuels [5]. The amount of energy used in industry is about 50% of the total demand [5]. Being in need of so much energy, there needs to be a constant supply. If solar would be an important source of electricity for the industry and all solar generated electricity is used immediately, there is not enough to keep the industry running in solar off-peak hours. This is one of the reasons of why gas is such a great way of producing electricity. Production is constant and can be adjusted to the demand if needed. Electricity production for industry can be done by green gases (biogas, hydrogen). For households, the demand is way lower than for industry. The consumption is usually lower than the solar production during peak-hours. hence, surpluses can be stored in order to be used later and still meet the demand.

It is clear that the energy landscape is changing. Local communities are becoming more active actors in the energy landscape. With households producing 15% of the emissions it is the third largest greenhouse producing sector (after industry and transport, 50% and 20% respectively) [6]. It might seem to be more logical to make changes in the other two sectors first, because a larger share of emission is being cut. But the households form a sector on which individual residents can have a large influence if they participate. As Koirala in [7, p.32] mentioned, "Citizens' participation in the energy system helps to enhance local support. It increases acceptance of renewables and adoption of energy efficiency measures and impacts beyond the limit of the local energy project". A survey was held among Dutch households, it showed that 80% of the respondents are aware of local energy initiatives. 53% of the respondents are willing to participate, either without or with minor responsibility. But only 8% are willing to have organizational responsibility by steering the system, e.g. by being a member of the board [7]. This already leads to an increase in distributed energy resources (DERs). As a result there are techno-economic changes in the power system, as can be seen in table 1.

	Traditional power system	Future power system
Technical	Centralized	Centralized and distributed
	Schedule supply to meet demand	Match supply and demand with flexibility, grid expansion, demand side management, storage and flexible back-up
	Passive network management	Active network management
	Flexibility from ramping-up and down, peak-power plants, interruptible loads, interconnection	Flexibility market, demand response, storage, interconnecection, curtailment
Economic	centralized day-ahead, intraday and balancing markets	Centralized and decentralized markets for energy and other services including flexibility
	CO_2 emissions are external	CO_2 emissions are internalized through carbon tax, carbon pricing
	Retail prices are in proportion to the wholesale prices	Mismatch between wholesale and retail prices due to increasing fixed costs
	Volumetric network tariffs	Advanced network tariffs
	Price inelastic consumers	Price elastic consumers

Table 1: Overview of techno-economic changes in the energy landscape [7, p.2].

The increasing use of renewables energy sources in worldwide energy systems is leading to an increase in stability and reliability problems. According to Koirala, "the key challenge of the future energy system is the integration of these increasing amount and types of DERs" [7, p.3].

Having distributed the energy sources, it becomes difficult to overlook and maintain them from a centralized point. Integrated community energy systems (ICESs) might be a solution to this. “Integrated community energy systems (ICESs) take advantage of cross-sectoral opportunities in the areas of land use, infrastructure, building, water and sanitation, transportation and waste to curb energy demand and reduce greenhouse gas emissions at the local level, while increasing energy security, enhancing the quality of life and realizing financial benefits for residents”[7, p.8][1]. Part of this energy security is by implementing innovative energy storage systems such that surpluses in energy generation will not get wasted. To meet local demands, the existing infrastructures and available resources in the community need to be investigated. Which sources can be used to produce energy? Where an how are storage systems placed? And a lot more question need to be answered in order to determine how ICESs will be formed.

Before such a system can be set up, a community size and other quantities need to be determined. There are multiple types of houses and each house has its own energy behaviour. Also the amount of people in a household influence the energy consumption. How energy can be generated and stored is depending on the area it will be placed. A flat might have room for storage systems on its roof. In a residential area containing only detached houses, a single storage system is unlikely to be placed on a rooftop.
Because storage is a very important part in an ICES, the research question stated below will help to set up an ICES in a community of 20 households consisting of the average household size in 2018, which is 2.15 [9].

Which storage system is most suited on a technical and social level for local usage? And how will the implementation of an ICES affect the community?

[1] From Harcourt et al (2012) [8]

2 Implementation and adaption of energy systems

2.1 Energy systems

As mentioned in the introduction, using integrated community energy systems is a way of distributing energy, but that is not the only system available. Other systems are:

- **Community microgrids**: consist of clusters of DERs that are controlled locally and are seen as single demand and supply from both electrical and market perspectives. They can be independent from the national grid and operate autonomously when needed. In this way local resources can be used for local demand. This leads to reduction in demand and an increase in efficiency of the energy delivery systems [7, p.39].

- **Virtual power plants (VPP)**: is created by forming flexible capacity (as with a power plant). This is done by aggregating the consumption and production of various households. There are two types of VPP, a technical and a commercial. A technical VPP location specificity attached to flexibility, mainly in a distribution system. A commercial VPP has no location specificity. Flexibility from a commercial VPP can be aggregated and distributed from different distribution systems. This allows for the participation of DERs into the energy market and a system operation support [7, p.39].

- **Energy hubs**: manage energy flows in a district through optimal dispatch of multiple energy carriers. These hubs include storage, conversion and distribution technologies to supply energy in different forms to the end users [7, p.39].

- **Prosumer community groups (PCGs)**: is a network of prosumers that have a relatively similar interests and energy sharing behaviour. Together they make an effort to pursue a mutual goal and jointly compete in the energy market. They are designed to overcome possible inflexibilities arising from microgrids and technical VPP such as adding or removing members. PCGs connect prosumers virtually and not necessarily technically [7, p.39].

- **Community energy systems**: is a local system that produces electricity and/or heat on a small scale that can be managed by and for local people that provide them with beneficial outcomes [7, p.39].

- **Integrated community energy systems (ICESs)**: capture attributes of all energy integrations mentioned above and apply it to a community level energy system. This helps re-organizing the local energy system and increase community engagement. In Koirala [7, p.39], an ICES is defined as "a multi-faceted approach for supplying a local community with its energy requirement from high-efficiency co-generation or tri-generation as well as from renewable energy technologies coupled with innovative energy storage solutions as well as all electric vehicles and demand-side measures. They aid in increasing self-consumption and matching supply and demand at the local level".

The different energy systems are shown in figure 1 below. *Value generation* refers to the value for the larger energy system. This can be achieved through collaboration and services to external systems, such as other communities. *Degree of integration* refers internal values, such as self-provision and self-sufficiency. ICESs and community microgrids both provide energy-related and network services and operating reserves through physical interconnection. ICESs rank slightly higher than the microgrids due to the higher community engagement and integrated operation of different sectors [7]. This is why it is chosen to elaborate more on ICESs.

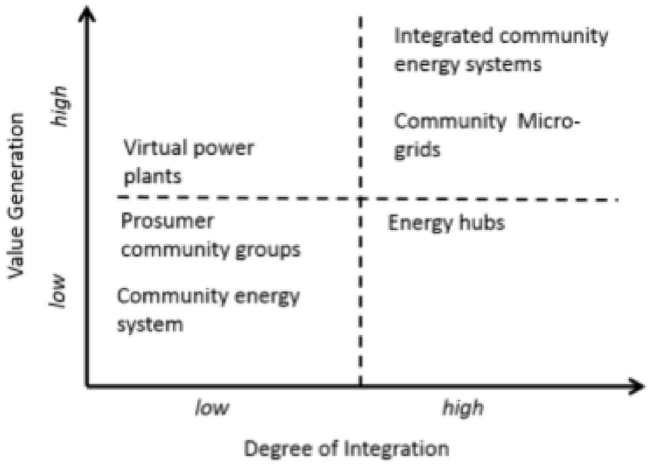

Figure 1: Interaction of value generation and degree of integration in different energy systems [7].

2.2 Integrated community energy systems

Nowadays, households are connected to a centralized power grid that provides them with gas and electricity. Due to technological progress and political recognition, community energy systems now form an important role in the energy transition.
A new energy system, such as ICES, is dependent on technological, economic and environmental issues. However, ICESs are not yet fully developed and without problems. There are still barriers that need to be overcome. The companies that have a large influence in the energy distribution now, might not have it in the future. This might be a reason for those companies to try and slow down or even stop the development of new local energy systems. How ICESs work and which problems they face, needs to become clear on order to come up with solutions.

Implementing ICESs are done for a couple of reasons. The aim of ICESs is to reduce energy costs, CO_2 emissions and dependency on the national grid. Other goals are to improve comfort and resistance to the utility. Developed countries and developing countries each have their own reasons to implement ICESs. For developed countries, increased climate awareness and willingness to become autonomous among pro-active communities are the drivers. Developing countries however, are driven by the accessibility of energy. Reducing the energy costs and CO_2 emissions are the driving factors for local communities.
The involvement of local businesses, resident and governments make the probability of successfully implementing ICESs larger.

2.2.1 Challenges

Installing a new energy system is not easy. Before this can be done, ICESs need to overcome some barriers and challenges. These challenges are in different factors involved when trying to install ICESs. The main barrier that needs to be overcome is due to how the energy system is arranged now. The present energy system is centralized, which means that production and controlling is done from a few locations. All designs and regulations have been adjusted to this energy landscape. Changing the form of the landscape means that designs and regulations need to be changed. However, when an influential institution (e.g. grid operator) prefers a centralized system, it might prevent the changes needed to implement ICESs, e.g. by not transferring ownership or leasing the network to the community. This leads to the need of a new grid, which increases the costs.
Assuming legislation will be changed and allow the rise of DERs, the willingness and interaction among civilians to maintain the system is needed. This is necessary because the present information flow is unidirectional, but this will change to a multidirectional system. Better interaction between civilians is needed because selling energy to neighbours is complicated and affordable and easy access to the grid for local generation can be complex and costly. Other costs involve utility bills, maintenance and operation costs, interconnecting households and contribution to the larger network, capital costs for DERs and the management system, and fuel costs. An overview of challenges is given in table 2.

Challenges	Description
Operation	Need for a service provider and/or expert companies for technical operation
Financing	Access to private finance, micro-finance and loans
Cost-benefit sharing	Fair allocation of costs among actors
Business case	A new business model for flexibility and other services
Monetization of services	Monetizing essential community and other ICESs services
Managing utility relations or grid issues	Access to network and costs recovery of its investment

Table 2: Challenges of ICESs [7, p.29].

Already in the participation part, citizens have a reason not to be part of the ICESs. These reasons are shown in figure 2.

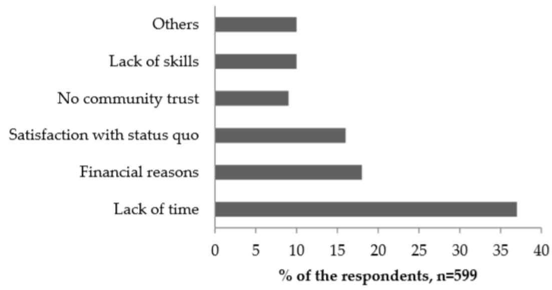

Figure 2: Problems that prevent joining ICESs [7, p.29].

As can be seen, lack of time is the main reason not to participate in ICESs. This means that they need to be convinced that the system will be such that it does not take much time to join ICESs and/or that the time consuming elements will be done by companies. Financial reasons might be overcome by explaining the financial benefits that come with joining ICESs. Benefits can be achieved without everyone investing in renewable sources. Because people are happy with the current system, they need to be reminded to the financial and environmental benefits that come with ICESs. This might convince them.
Other reasons include, too much focus on environment, trust in government, limited thinking space, too big risk, already owning solar panels and heat-pumps, expectation of government initiative, financial sustainability, inclusive rent, old age, moving in the near future, renting, no interest in initiative and leadership, lack of experience, already participating.

2.2.2 Function and contribution

Local balancing and strategic exchanges with individual households within a community and neighbouring communities and the national energy system need to be achieved by interaction and coordination of ICESs. Ancillary and balancing services to the national energy system are process that can be provided by ICESs. They enable individual household to participate in different energy markets by merging them. The figure below shows the functions and interaction of an ICES.

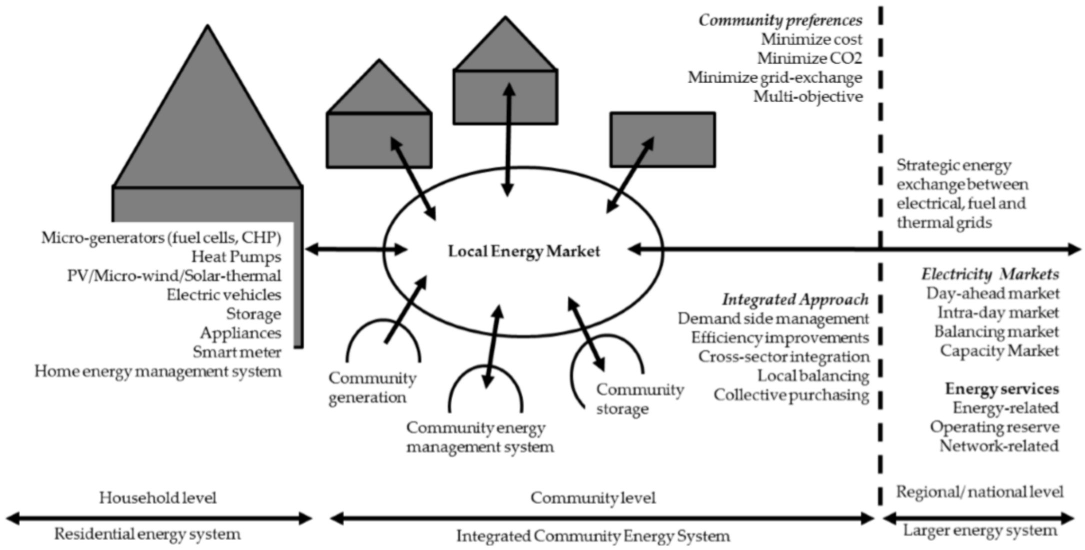

Figure 3: The functions and interaction of an ICES [7, p.29].

The contribution of ICESs for different stakeholders is shown in table 3.

Community	System operator	Policy-maker
- Protect against price fluctuations - Modular in development - Reliable - Resilient - Economic benefits (savings and revenue generation) - Grid support within ICESs - Higher efficiency - Integrated - Improved power quality - Sense of community	- Improved reliability of energy system - Grid support (services and flexibility) - Occasional roles as service providers - Investment suspensions	- Higher energy efficiency - Higher renewables penetration - Local economic growth - Increased energy security - Environmental benefits - Sustainability

Table 3: Contribution of ICESs [7, p.30].

2.2.3 Characterization and categorization

In order to implement ICESs, an existing energy system does not need to be in place depending on the local system. Local energy systems can be identified based on the following characteristics [7, p.24]:

- **Locality**: a large proportion of investment and ownership should be from locals. Also the generation and storage should be local and be used for self-provision through local energy exchange.
- **Modularity**: the entry and exit of members needs to be handled by the system. To adapt to the rising demand, household and community level technologies can be added later.
- **Flexibility**: can be achieved through local demand response and balancing and a flexible load and supply. Flexibility can be used to provide energy and system services.
- **Intelligence**: the information and energy flow need to be coordinated to match the local supply and demand.
- **Synergy**: should be allowed by the system, between different sectors, such as electricity, heat and transport and between different technologies.

- **Customer engagement** customers should be engaged by the system through different means, such as, investment, ownership, local energy exchange and economic incentives.
- **Efficiency**: the system should be efficient on a technical and an economical area.

Based on these characteristics and goal of the ICESs, different groups can be made. These groups can be categorized based on what is done with the system, how large it is and some other aspects, which are mentioned below.

Group	**Categorization**
Activities	Electricity generation including storage Heating/cooling including storage Collective purchasing Energy management and demand response Energy exchange and trading
Scale	Large/macro: city, region Medium/meso: neighbourhood Small/micro: household/buildings
Grid connection	Connected grid Off-grid
Initiatives	Led by citizens (energy cooperatives or business and collective procurement) Led by government with citizens (parcipative area development and goverment initiatives)
Location	Developed countries-urban Developed countries-rural Developing countries-urban Developing countries-rural
Topologies	State of the art integration of DERs Integration through common point of coupling Autonomous ICESs

Table 4: Categorization of ICESs [7, p.38].

3 What sorts of energy storages are available?

There are dozens of ways to store energy. Batteries are probably the best known storage systems. Batteries are electrochemical storages, but energy can also be stored in other types of storages. For example, a mechanical storage system, which can use a turbine in order to produced electricity from the stored energy sources (e.g. elevated water, compressed air). Electrical and magnetic storage systems can also be used to generate electricity. Gases can be considered as energy sources, but also as energy carriers, depending on the type of gas. What makes gas so suitable is that it can be stored easily and that it can be used to generate electricity as well as heat. Heat can also be used to store energy, thermal storage as it is called, which is mostly used for heating spaces and not for cooking because the temperatures do not get high enough.
These overlapping energy storage types contain a lot of storage systems. These storage systems are listed in appendix A.2[10][11].

3.1 Applicability

To see which energy storage system is most useful, a couple of characteristics need to be taken into account. These characteristics are listed in appendix A.1.
The (dis)charge time and power and their respective response times are very important technical aspects of a battery. For the investors however, the costs, safety and the lifetime of a system are also important [10]. Hence, there is a lot that needs to be taken into before a system can be installed.
To make sure surplus energy does not get wasted, it needs to be stored as quickly as possible. For this the charge time and its response time need to be low to make sure the battery can be refilled quick. When the electricity demand is fluctuating a lot, the system needs to be capable of delivering at all times. In order to make this happen, the discharge response time needs to be low. But it is unwanted to quickly drain the saved energy, so the discharge time needs to be high.

Looking at these qualities, the group of batteries mentioned in appendix A.2 can be thinned out. The mechanical and electrical storage systems (1-4 in app.A.2) are not viable for community usage. Pumped hydro storage and compressed air storage be neglected further in this paper due to their size and geographic requirements. Also supercapacitors and flywheels are not suited, because they are not capable of meeting the specific energy and power requirements [12]. Using a SMES is a very efficient way of storing energy. Because the system has to be cooled to $\sim$60K, a lot of energy is is used to achieve that, so this affects the efficiency. Including the cryogenic loses, the efficiency is still over 90% [13]. A SMES can be build as large as needed, but the costs to build them are very high [14][15]. The prices are expected to drop, but they need to go down a lot if they want to compete with other storages, which might not be as efficient, but have a higher energy density and are cheaper.

Looking at electrochemical storages (6-8 in app.A.2), they all suit the requirements mentioned and single cells can be coupled in order to obtain the needed capacity. Lead acid batteries have some drawbacks. They need to be operated correctly (no deep discharging), or the lifetime decreases quickly, toxic materials are used (lead, sulfuric acid) and have a potential for producing explosive gas mixtures in enclosed areas [11]. This can cause unwanted public objection, hence this will not be used. Looking at lithium ion batteries, the only disadvantage really is the price. Which is also expected to decrease throughout the years [11]. So lithium ion batteries are a good option to use on a community level. A vanadium redox flow battery is a relatively new type of battery. It can be made to suit certain requirement like power and energy. Containing only vanadium, no cross contamination can arise and no side reactions can take place. This prevents loss in power and capacity and increases the lifetime drastically compared to other electrochemical storages [16]. However, due to its low energy density, the system is not suited for a house [15].

Using hydrogen to store electricity and later get electricity out of the hydrogen again is very inefficient. It has an efficiency of 30-50%. Hydrogen might be used to replace natural gas for heating houses, since the efficiency of producing hydrogen by electrolysis is 70-85% [17].

Storing methane and natural gases (10-12 in app.A.2) is something that cannot be considered when electricity is needed to be stored. But when it comes to heating houses, these gases are a very option. Natural gas is a great way of storing energy, but it is needed to become independent of fossil fuels due to the large amount of greenhouse gases they produce when burned. Hence, storing (liquefied) natural gas is not an option. Storing methane can be an option, but this needs to be produced in a green way (e.g. digesting or using hydrogen & carbon dioxide).

The thermal storages (13-16 in app.A.2) are potential storages to regulate the heating of houses. Hot water and underground thermal storage (UTS) are good ways to provide heating in houses. Molten salt is a very efficient way to generate heat, but such a system would need a large surface area, which is not available in a small community. Latent heat has a high energy density storage compared to thermal heat, seemingly making it a good option. However, just as for a molten salts setup, the initial investments are four times larger than a UTS and even 40 times larger than just using hot water [15]. This makes using molten salt and latent heat not a likely option for heating houses.

As long as vanadium redox batteries have such a low energy density, lithium-ion batteries are the best possible storage system to use on a household level.

4 Scenario planning

The yearly energy consumption is really dependent on the type of residence you live in and with how many, as can be seen in tables 6 and 7. Table 7 might take all-electric houses into account, but since the majority of the houses is from before 2000 [18], the majority still uses gas for heating and/or cooking. If the residence uses gas, the electricity is lower than for an all-electric house. An all-electric house is heated using a heat-pump instead of gas and a gas stove is replaced by an induction plate or an electric stove.

How large the electricity storage needs to be, depends on how much electricity is generated and consumed. The generation can be done by wind turbines and solar cells. Here, solar cells are used to generate the electricity because they are already more used for household electricity generation. A solar cell has a maximum yearly power production, this is expressed in watt-peak (Wp). Depending on the global position of the solar cells, a yearly amount of energy is generated. In the Netherlands, 1 Wp generates 0.90 kWh per year [19].

The diversity among solar cells is huge, but the main difference between them, is the type of cell used to generate electricity (e.g. crystalline silicon cells, cadmium telluride cells, perovskite cells etc.). For household application, mono-crystalline silicon solar cells are used because of their price/quality balance. There are many companies producing solar panels. After some research, it has been chosen to work with *LG* panels and *SolarEdge* inverters and optimizers. This because the prices and specifications of these systems could be found. The panels used are chosen to be *LG400N2T-A5 Mono Neon2 BiFacial 400Wp*. This panel has an efficiency of 98% in the first year, after that, there is a yearly degradation of 0.35%. In the 25^{th} year, the efficiency is at 89.6% [20]. An all-electric house with a heat pump consumes a lot of electricity, hence it is chosen to use a panel with a high maximum power output. Based on a quotation from *Woortman BV*, the costs for a frame and a connection kit per panel is approximated to be €78.26. The power optimizer used is the *SolarEdge P404*, because it suits the panel used. Its costs are €49.00 per optimizer [21]. Installation costs are extrapolated from [22, p.4] and assumed to be given by; costs = 49,916x + 431,42, where x is the amount panels installed.

The yearly generated electricity does not get generated evenly among all months throughout the year. This is due to seasonal changes. The calculated generated percentage each month is shown in table. These calculations assume an angle of the roof of 50°. The solar radiation is taken into account, the possible shade is not taken into account [23].

Month	% from yearly production	Sunshine hours
January	2.6	42
February	4.3	70
March	8.5	138
April	12.1	197
May	13.4	218
June	13.2	214
July	13.0	211
August	11.4	185
September	9.2	149
October	7.0	114
November	3.3	54
December	2.0	32

Table 5: Monthly production percentage of yearly production [23].

For further calculations, it is assumed that these percentages are generated evenly among the days in each month (e.g. on a single day in January, $1/31^{th}$ from 2.6% is produced).
Two types of residences have been chosen to study in this paper. These are a residence which uses gas for heating of spaces and water and cooking, an all electric residence, which does not use any gas. After this, a future prediction on consumption and production is done. It is assumed that everything is 25% more efficient in 2050 [24]. This means that consumption decreases with 25% and production increases with 25%.

4.1 Gas and electricity consuming house

Using the data in table 7, the electricity consumption for an average household size (n=2.15 persons) can be estimated using a second polynomial function

$$kWh = -122.68 * (n^2) + 1343.3 * n + 734 \tag{1}$$

With n being the number of people in a household. For n=2.15, this leads to an average yearly electricity consumption of 3055 kWh.

Home type	Average yearly consumption (m^3)
Flat	1000
Town house	1350
Corner house	1580
Semi detached	1800
Detached	2410
Average all houses	1470

Table 6: Average yearly gas consumption for different types of houses [25].

Number of persons in a household	Average yearly consumption (kWh)
1	1925
2	3005
3	3605
4	4155
5	4375
6	4385
Average per household	2990

Table 7: Average yearly electricity consumption for different sizes of households [25].

In order to cover a yearly consumption of 3055 kWh, the solar panels need to have a Wp of

$$Wp = \frac{1}{0.90} * 3055 = 3394Wp \tag{2}$$

4.1.1 Solar panel pricing and payback time

A detached house with a yearly electricity consumption of 3055 kWh needs to have solar panels which can deliver at least 3394 Wp. It is chosen to work with LG panels that have a maximum power of 400 Wp. This means that 3394/400 = 8.5 $\rightarrow$ 9 panels need to be installed. 9 $\times$ 400 = 3600 Wp. This is the minimum output an inverter has to have, looking at the specifications for multiple *SolarEdge* optimizers [26], the *SE3000H* suffices and costs €799 [27]. The total costs for purchasing and installing these panels with the required equipment is

Part	Price (€)
Panels	9×302
SE3000H	799
Installation	49,916×9 + 431.42
Frame + connection kit	9×78.26
Optimizers	9×49
Total	**5543.00**

Table 8: Purchase and installation price for nine 400 Wp LG solar panels.

The theoretical value of electricity that is generated each year is 3600·0.90= 3240 kWh. To determine the yearly costs saved with solar panels, the following equation is used:

$$\sum_{n=0}^{n} [(3240 \cdot 0.98(1 - 0.0035)^n) \cdot (0.23(1 + 0.017)^n)] \tag{3}$$

with n=0 being the year of installation. From this, it can be determined that the payback time is ∼6.5 years.

4.2 All-electric house

An all-electric household has the same basic electricity consumption as a house that uses gas for heating and cooking, but now the heating and cooking are done using electricity. This increases the amount of electricity used and drops to gas consumption to 0.

Heating is done using a heat-pump. There are a different types of heat-pumps. They are listed below [28]:

1. Air-water heat-pump: uses the air outside as heat source. The heat is then used to heat the residence or tap water.
2. Air-air heat-pump: uses air from outside as heat source and is used to heat the residence. So no water is heated by this system.
3. Ground-water heat-pump: gets heat from the ground to heat the residence and tap water. This requires the installation of underground tubes. Drilling is needed in order to make this happen.
4. Water-water heat-pump: uses the constant temperature of ground water for heating the residence and tap water. Drilling is required to make this possible.
5. Hybrid heat-pump: is a combination of a heat-pump and a gas boiler. It uses the outside heat as a primary source, but when the temperature gets to low, the boiler is used to heat the residence.

A hybrid pump is not an option, because it still uses gas. An air-air pump can not heat water, hence an other source is needed to heat the water. For simplification reasons, this pump is neglected. The other three types of pumps are all suitable. The difference between the water-air heat pump and the water/ground-water heat pump is that the latter one has a higher efficiency when the temperature outside gets colder. However, because drilling is required, the price tag is higher for those pumps than for an air-water pump.

There is also the PVT system, which is a combination of a photovoltaic and a photothermal system to heat the residence and tap water. Because of the high temperature in solar cells at sunny days, the efficiency of the PV system decreases. A PVT system transfers this heat to the buffer vessel and keep the PV system at its optimum temperature. However, this system is also depending on the weather. In the winter, less heat is generated by the system and an additional heat source is needed [29]. A new system has recently started its test phase. This PVT system is able to produce enough electricity to power a heat pump at -10°C [30]. The price of this new system is unknown. For the existing systems, the price is about twice as high as an equivalent PV system [29]. Since the older systems need an additional heat source, which brings additional calculations and costs depending on the source into the picture, and there a no prices of the newer systems to be found, a PVT system is not taken into account any further.

What is needed for all heat-pumps is a buffer/boiler vessel or a post heating system. Because a heat pump can not heat water quickly, a vessel that keeps water at a higher temperature is needed in order to quickly supply warm water. Such a vessel contains heating coils that can be heated by different power sources (e.g. solar panels). Such a vessel can contain multiple layers of differently heated water [31], such that it suits different applications. A post heating system is needed when the outside temperature is too low to heat the house.

A heat pump has a so called coefficient of performance (COP). This is a number that represents the energy needed to pump heat from a source and the heat that is produced by the system. E.g. a system having a COP of 4.5 can produce 4.5 kW of heat from 1 kW of electricity. The COP is depending on the outside temperature and the release temperature of the system. When the difference between these temperatures gets smaller, the COP increases. When using the outside air as a source, the COP really fluctuates due to the seasonal temperature changes. The seasonal coefficient of performance (SCOP) averages these changes in the COP throughout the year. In order for a heat pump to be beneficial with respect to a gas boiler, the system needs to have a minimal COP. This can be seen in figure 4. The y-axis shows the price per kW heat and the COP of a heat pump can be seen on the x-axis. From a COP of 2.9 and higher, a heat pump is financially more favourable than a gas boiler [32]. In order for a heat pump to be effective, a house needs to be insulated properly. Usually, only houses build after 2000 have a proper insulation [33]. However, the possible necessity of improving the insulation and hence increasing the costs is neglected. This is done for simplification reasons. These costs can differ a lot between individual houses. Hence, it is assumed that the insulation allow the implementation of heat pumps.

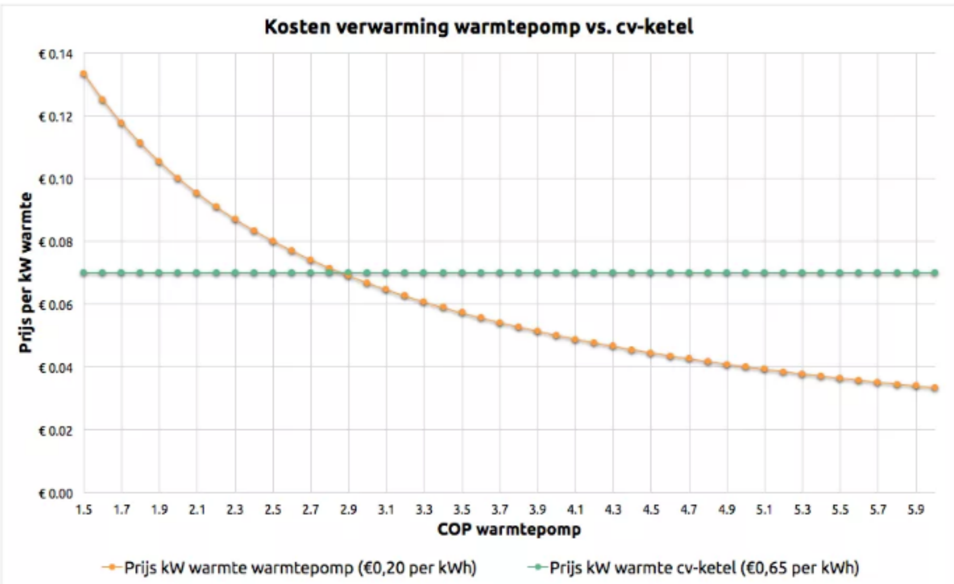

Figure 4: Costs of heating with a heat pump compared to a gas boiler. The orange line represents the heat pump and the green line represents the gas boiler [32].

4.2.1 Pricing and pay-back time of heat pumps

A water-water system is might be difficult to use. This is because this system is very dependent on the geographical layout. Hence, only the following systems will be compared: an air-water heat pump and a ground-water heat pump. A heat pump replaces the gas consumption used for heating. It is assumed, based on online readings, that 80% of the gas consumption is used for heating application and 20% is used for cooking. For heating, the consumption is 2410 × 80% = 1928 m^3.

4.2.1.1 Air-water heat pump

For a standalone air-water heat pump with a boiler vessel, the purchase and installation costs are €8538 incl. V.A.T [34] (€7865 for the system and (€6238-(€7865-€2300[2]))[3] = €673 for the installation). Assuming a SCOP of 4 [33, p.9], the yearly gas consumption for heating of a detached house (1928 m^3) can be replaced by the following amount of energy:
In 1m^3 of gas, there is 8.8 kWh of energy delivered by a gas boiler [36].

$$1928 \times 8.8 = 16,966kWh \tag{4}$$

With a SCOP of 4, the electricity consumption increases with:

$$16966 : 4 = 4242kWh \tag{5}$$

With an electricity price of 0.23€/kWh and a gas price of 0.79/kWh in 2019 [36], and an increase in gas and electricity price of 1.3% per year and 1.7% per year respectively over the last 10 years [37]. Which is assumed to remain the same. The yearly saved energy costs is given by

$$\sum_{n=0}^{n}(1928 \cdot 0.79(1+0.013)^n - 4242 \cdot 0.23(1+0.017)^n) \tag{6}$$

With n being the number of years. $n = 0$ is the year of installation. This lead to a pay-back time of $\sim$14 years when purchased without subsidy. If it is purchased with a subsidy of €2300, the pay-back time is $\sim$10 years.

A standard gas boiler has a lifetime of $\sim$15 years, but a heat pump has a lifetime of $\sim$30 years. An air-water heat pump earns itself back in a third of its lifetime. After 30 years,

$$\begin{gathered}\sum_{n=0}^{29}(1928 \cdot 0.79(1+0.013)^n - 4242 \cdot 0.23(1+0.017)^n) - \text{investment} \\ 17678 - 8538 = 9140\text{euro}\end{gathered} \tag{7}$$

is saved.

According to the EPA, natural gas emits 1.95 kg CO_2/m^3 and grey electricity 0.45 kg CO_2/kWh. There is a little difference in the amount of electricity generated and actually delivered. This is taken into account by multiplying with $\frac{1}{1-0.071}$ [38]. This leads to a yearly CO_2 emission reduction of:

$$1928 \cdot 1.95 - \frac{4242 \cdot 0.45}{1 - 0.071} = 1705\text{kg of CO}_2 \tag{8}$$

4.2.1.2 Ground-water heat pump

A ground-water heat pumps' costs are depending on the maximum heat demand. On [39], a well insulated four person household detached house is used as an example. According to table 6, the amount of persons has no influence on the gas (heat) demand. Hence, the maximum heat demand mentioned on [39] (13,750 kW at -10°C) is used here as well. Two systems are worked out below. A standalone ground-water heat pump and one in combination with an additional electrical heating element. The ground-water heat pump is assumed to have a SCOP of 4.75 [33, p.9].

[2] Subsidy is subtracted because it is only available till 2021 [35].
[3] Numbers from [34], €2300 from subsidy, €6238 for system and installing incl. V.A.T.

A standalone system has a so called beta factor of 1. This means the heat pump has to be able to deliver the complete 13,750 kW of heat on its own. In order to do this, the pipe system is larger than for the combination setup. The price of this system is €18,474.50, without the subsidy of €2800. €7831 for the heat-pump, €1028.50 for the boiler vessel, €8250 for the construction of the ground source and €1815 installation costs [39].
With this system having a SCOP of 4.75, the electricity consumption increases with:

$$16966 : 4.75 = 3572kWh \tag{9}$$

This leads to the following amount of energy costs saved per year:

$$\sum_{n=0}^{n}(1928 \cdot 0.79(1+0.013)^n - 3572 \cdot 0.23(1+0.017)^n) \tag{10}$$

This leads to a pay-back time of ~23 years without subsidy. With subsidy, the pay-back time is ~20 years.
This gives a yearly reduction in CO_2 emission of

$$1928 \cdot 1.95 - \frac{3572 \cdot 0.45}{1-0.071} = 2029\text{kg of CO}_2 \tag{11}$$

After 30 years,

$$\begin{gathered}\sum_{n=0}^{29}(1928 \cdot 0.79(1+0.013)^n - 3572 \cdot 0.23(1+0.017)^n) - \text{investment} \\ 18480 - 18474.50 = 5.50\text{euro}\end{gathered} \tag{12}$$

is saved.

In the second system, the heat pump has a beta factor of 0.7, which means that it only has to be able to supply 70% of the 13,750 kW. The other 30% is supplied by the additional heating element. With a beta factor of 0.7, less than 5% of there is a lack in power supply. Because -10°C is rarely ever reached anymore. This means that 95% of the 21,208 kWh is used by the heat pump and 5% by the heating element, which has a COP of 1. This system costs €15,758.50 without €2800 from a subsidy. €7139 for the heat-pump, €1028.50 for the boiler vessel, €5775 for the construction of the ground source and €1815 installation costs [39]. Construction costs are lower than for a standalone system because the pipes do not need to be as deep into the ground.

$$\begin{gathered}\text{Heat pump} \quad 16966 \times 95\% = 16,118kWh \\ \text{Heating element} \quad 16966 \times 5\% = 848kWh\end{gathered} \tag{13}$$

This gives an electricity consumption increase of:

$$(16118 : 4.75) + 848 = 4241kWh \tag{14}$$

Yearly cost savings is given by:

$$\sum_{n=0}^{n}(2410 \cdot 0.79(1+0.013)^n - 4241 \cdot 0.23(1+0.017)^n) \tag{15}$$

Without subsidy, the pay-back time is ~26 years. With subsidy, it is ~21 years.

Which leads to a CO_2 emission reduction of 1705 kg per year, which is the same as an air-water heat pump. The savings after 30 years however, differ a lot.

$$\begin{gathered}\sum_{n=0}^{n}(2410 \cdot 0.79(1+0.013)^n - 4241 \cdot 0.23(1+0.017)^n) - \text{investment} \\ 17686 - 15758,50 = 1927.50\text{euro}\end{gathered} \tag{16}$$

The ground-water heat pump however, has one advantage over an air-water heat pump. If cooling is required, a ground-water heat pump can do this passively while an air-water heat pump has to do this actively. This means that there are no costs for cooling with a ground-water system. Cooling is not much required in the Netherlands, hence additional costs for cooling are not taken into account.

4.2.2 Total electricity consumption

Because the houses are all-electric, cooking is done using induction stoves. This is because induction stoves use less electricity than ceramic stoves, their prices are a bit higher (€568.77[4] for induction and €410.28[5] for ceramic), but this can be earned back because of the lower energy consumption from induction stoves. The yearly energy consumption for induction is 175 kWh, compared to 225 kWh for ceramic cooking [40]. It is assumed that the time spent cooking is the same each day throughout the year. This results in a daily energy consumption spent on cooking of 0.48 kWh. This is taken into account when determining the capacity of a storage system.

20% from the consumed gas is used for cooking, this is 482m^3 for the case studied. One year after installation,

$$\sum_{n=0}^{n}(482 \cdot 0.79(1+0.013)^n - 175 \cdot 0.23(1+0.017)^n) \tag{17}$$

€685 is saved on energy costs. This shows that the stoves' costs are earned back within a year. When installation is done by a handyman, it can be a bit over a year, depending on the price. And yearly CO_2 emissions are reduced by

$$482 \cdot 1.95 - \frac{175 \cdot 0.45}{1 - 0.071} = 855\text{kg of } CO_2 \tag{18}$$

Combining the electricity consumption of the induction plate with that of the different heat pumps, the total yearly consumption for each combination is

Initial consumption (kWh)	Induction (kWh)	Air-water (kWh)	Ground-water (kWh)	Ground water + heating element (kWh)	total (kWh)
3055	175	4242	N.A.	N.A.	7472
		N.A.	3572	N.A.	6802
		N.A.	N.A.	4241	7471

Table 9: The total yearly electricity consumption of an all-electric house with different combinations of heat sources. The initial consumption is from table 7.

4.2.3 Solar panel pricing and payback time

The number of solar panels needed to cover these yearly electricity consumption is

Scenario	Consumed kWh	Wp needed	# panels needed	Generated kWh
Air-water heat pump	7472	8269	21	7560
Ground-water heat pump	6802	7558	19	6840
Ground-water heat pump + heating element	7471	8268	21	7560

Table 10: Numbers of panels needed to cover electricity consumption for an all-electric house with different heat pumps and the theoretical amount of electricity they generate on a yearly basis.

Now the inverter SE6K (€1269 [41]) for the air-water heat pump and the ground-water heat pump + heating element. The SE7K (€1289 [42]) is used for the ground-water heat pump [43]. The costs for the

[4] Average price for built-in induction stoves with a least four cooking zones given at Kieskeurig.
[5] Average price for built-in ceramic stoves with a least four cooking zones given at Kieskeurig.

installations are

Air-water heat pump and Ground-water heat pump + heating element

Part	Price (€)
Panels	21×295
SE7K	1289
Installation	49.916×21 + 431.42
Frame + connection kit	21×78.26
Optimizers	21×49
Total	**11,636.12**

Table 11: Purchase and installation price for 21 400 Wp LG solar panels.

Ground-water heat pump

Part	Price (€)
Panels	19×302
SE6K	1.269
Installation	49.916×19 + 431.42
Frame + connection kit	19×78.26
Optimizers	19×49
Total	**10,804.76**

Table 12: Purchase and installation price for 19 400 Wp LG solar panels.

For the systems corresponding to table 11, the payback time of the solar panels is found using

$$\sum_{n=0}^{n}[(7560 \cdot 0.98(1-0.0035)^n) \cdot (0.23(1+0.017)^n)] \tag{19}$$

and is found to be ∼5.5 years.

For the ground-water heat pump, corresponding to table 12, the payback time of the solar panels can be found using

$$\sum_{n=0}^{n}[(6840 \cdot 0.98(1-0.0035)^n) \cdot (0.23(1+0.017)^n)] \tag{20}$$

and is found to be ∼5.5 years.

The profit solar panels have after they have earned themselves back can be used to help pay back the investment made in the heat pumps. Hence, combining heat pumps with solar panels helps to reduce the payback time of heat pumps. The payback time of the total investment (heat-pump, induction stove and solar panels) is given by

$$\sum_{n=0}^{n}[[(2410 \cdot 0.79(1+0.013)^n - (175 + C - P \cdot 0.98(1-0.0035)^n) \cdot 0.23(1+0.017)^n] \tag{21}$$

Where C and P are the consumption and solar production respectively in each scenario.

Scenario	Total investment (€)	C (kWh)	P (kWh)	payback time (year)
Gas and electricity*	5543.00	3055	3240	∼6.5
Air-water	20,742.89	7442	7560	∼10
Ground-water	29,848.03	6802	6840	∼14
Ground-water +heating element	27,963.39	7441	7560	∼13

Table 13: The total investment for all scenarios and their respective payback time without subsidies.
* mentioned for comparison.

4.3 Future (2050)

In 2050 it is assumed that there are no longer any gas consuming houses. Also material costs are assumed to remain the same. With the consumption decreasing 25%, the electricity consumption decreases to 3055·0.75 = 2291,75 kWh for a house that uses gas and electricity and initially to 16966·0.75= 12.724,5 kWh for an all-electric house. After implementing the heat-pump and induction stove, the future consumption for each scenario is

Scenario	Present consumption (kWh)	Future consumption (kWh)
Air-water	$\frac{16966}{4}$ + 3055 + 175 = 7442	$\frac{12724.5}{4 \cdot 1.25}$ + 2291.75 + 175·0.75 = 4967.90
Ground-water	$\frac{16966}{4.75}$ + 3055 + 175 = 6802	$\frac{12724.5}{4.75 \cdot 1.25}$ + 2291.75 + 175·0.75 = 4565.17
Ground-water + heating element	$\frac{16966 \cdot 0.95}{4.75}$ + 16966·0.15 + 3055 + 175 = 7441	$\frac{12724.5 \cdot 0.95}{4.75 \cdot 1.25}$ + 12724.5·0.15 + 2291.75 + 175·0.75 = 5094.29

Table 14: A comparison of the present day consumption for the different scenarios and the future consumption.

A solar panel that in the present has a maximum power of 400Wp, now has a maximum power of 400·1.25 = 500 Wp in 2050. The 98% efficiency of the panels in the first year is assumed to be 100% in 2050 and the yearly decay of 0.35% is assumed to be 0.0035·0.75 = 0.002625 = 0.26%.

Scenario	Consumed kWh	Wp needed	# panels needed	Generated kWh
Air-water heat pump	4967.90	5519.89	12	5400
Ground-water heat pump	4565.17	5072.41	11	4950
Ground-water heat pump + heating element	5094.29	5660.32	12	5400

Table 15: Numbers of panels needed to cover electricity consumption for each future scenario and the theoretical amount of electricity they generate on a yearly basis.

Using the same calculation as in tables 8, 11 and 12, only with a different inverter. The SolarEdge SE4000H (€917 [44]) is chosen to be used for all scenarios. Inverters with a lower input power can be used, but because they are less commonly used, they are more expensive. The installation and purchase costs for the 11 panel installation is €6619,36. For the 12 panel installation, this is €7098,53.

Using

$$\sum_{n=31}^{n} \left[(2410 \cdot 0.75) \cdot 0.79(1+0.013)^n - ((175 \cdot 0.75) + C - P(1-0.0026)^{n-31}) \cdot 0.23(1+0.017)^n\right] \tag{22}$$

It starts from n=31 in order to take the price growth to 2050 into account. The solar panel factor has a power of n-31 because the panels are installed at n=31 and only start to lose efficiency from then on.

Scenario	Total investment (€)	C (kWh)	P (kWh)	payback time (year)
Air-water	16,205.30	4967.90	5400	∼6
Ground-water	25,662.63	4565.17	4950	∼10
Ground-water +heating element	23,425.80	5094.29	5400	∼9

Table 16: The total investment for all scenarios and their respective payback time.

5 Storage capacity

The capacity a storage depends on the largest difference between the consumption and production. A storage system has to be able to cover the largest surplus generated throughout the year. Based on the data provide by Mr. Benders, the largest surplus is generated in June. From table 5, it can be seen that solar panels produce 13.2% from the yearly production. For each scenario, this is

Present day scenario	**Yearly production (kWh)**	**Production June (kWh)**	**Consumption June (kWh)**
Gas and electricity	3240	427.68	223.06
Air-water heat pump	7560	997.92	543.38
Ground-water heat pump	6840	902.88	496.65
Ground-water heat pump + heating element	7560	997.92	543.31

Table 17: Production and consumption in June for the different scenarios.

Future day scenario	**Yearly production (kWh)**	**Production June (kWh)**	**Consumption June (kWh)**
Air-water heat pump	5400	712.80	362.73
Ground-water heat pump	4950	653.40	333.33
Ground-water heat pump + heating element	5400	712.80	371.96

Table 18: Production and consumption in June for the different scenarios.

Since the assumption that the production is distributed evenly among the days each month has been made and that based on the data provided by Mr. Benders, the consumption can also assumed to be evenly distributed among the days, the capacity is the daily difference of production and consumption. And since a lithium-ion battery costs are 250 €/kWh [15], the total costs for the battery systems are

Present day scenario	**Capacity (kWh)**	**Price (€)**
Gas and electricity	6.82	1705.00
Air-water heat pump	15.15	3787.50
Ground-water heat pump	13.54	3385.00
Ground-water heat pump + heating element	15.15	3787.50

Table 19: The capacity (daily difference) of the batteries needed and their prices.

Future day scenario	**Capacity (kWh)**	**Price (€)**
Air-water heat pump	11.67	2917.50
Ground-water heat pump	10.67	2667.50
Ground-water heat pump + heating element	11.36	2840.00

Table 20: The capacity (daily difference) of the batteries needed and their prices.

6 Battery distribution

Prosumers have two options on how to distribute their surplus energy. Via a peer to grid network (P2G), in which the surplus is transferred back to the main grid and the prosumer gets a compensation. Which means, they get (part) of the electricity price for every kWh they transfer to the grid. The second option is using a peer to peer grid (P2P). In which surpluses can be transferred to consumers in the same community [45]. The P2P network is better in terms of self-sufficiency and energy price, than the P2G, as can be seen in app. C. This also shows that This means that in a community consisting of 20 households, not everyone has to produce and store their own energy. In an ICES, prosumers have their own battery which is filled by their own production (through solar in this case). If consumers are in need of energy, they can get it from prosumers in their neighbourhood.

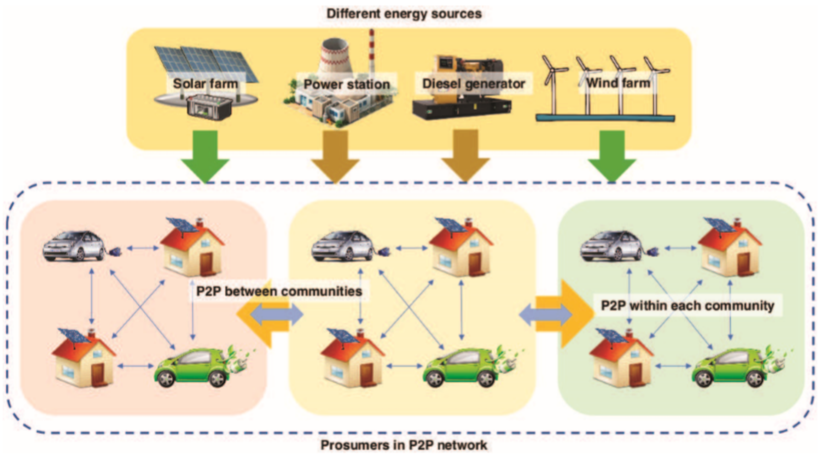

Figure 5: Demonstration of how a P2P energy network ca contribute to attenuate the dependency of the main grid [45, p.3].

As can be seen in tables 19 and 20, the individual battery capacity ranges from 6.82 to 15.15 kWh. Looking in the figure below, for a 20 household sized community, the self-consumption is 60%-90% and the self-sufficiency is 25%-33%. It can be seen in figure 6c, the annual energy price is between 375-450£. As the currency implies, this is not based on the Dutch system, hence prices can differ. But it shows the general idea of a decrease in price with a higher battery capacity.

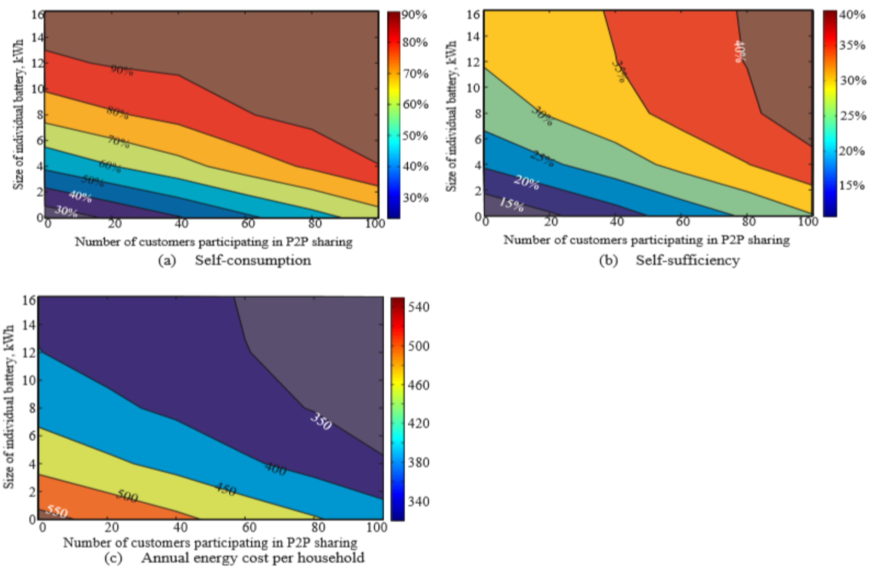

Figure 6: Performance metrics with varying number of customers participating in P2P sharing and varying battery sizes [46, p.273]

7 Peer to peer network

A P2P network is still in development, hence it is unknown how it eventually will take shape. A possible way of shaping a P2P network is in a *four-layer system of peer to peer energy trading*.
As can be seen in figure 7, the system consists of three dimensions and one of these dimensions (dimension 1) consists of four layers.

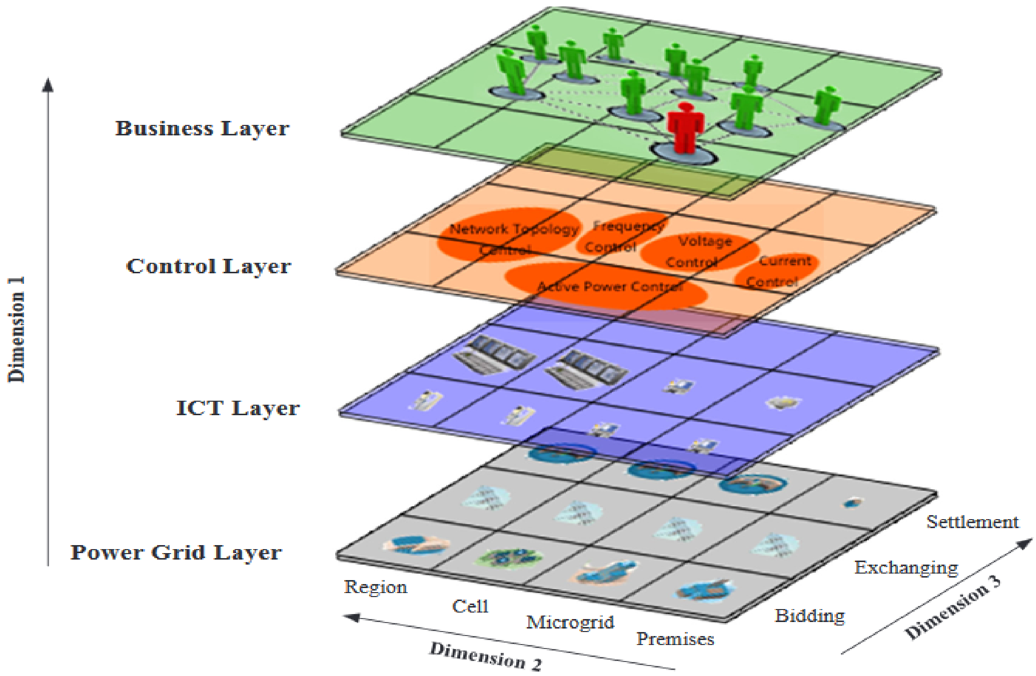

Figure 7: Visual representation of a four-layer system architecture of peer to peer energy trading [47, p.3].

The first dimension consists of four layers. Each layer represents a key function involved in P2P energy trading.
The power grid layer consists of all physical components of the system. This includes feeders, smart meters, transformers, DERs, etc. This layer forms the electricity distribution network [47].
The ICT layer consists of information flows through communication devices, protocols and applications. Communication devices can be: sensors, wired and/or wireless connections, routers, switchers, servers and computers. The protocols that need to be taken into account are: CP/IP(Transmission Control Protocol/Internet Protocol), PPP (Point-to-PointProtocol), X2.5, etc. And communication applications can for example be information transfer and file exchange. Each message transferred through the communication devices are part of the information flow .
The control layer consists of functions that control the electricity distribution system. Different control systems are defined for preserving a reliable power flow. The control functions mentioned in figure 7 are examples of functions to make this happen.
The business layer is there to determine how electricity is traded among peers and third parties. There are various models that could be developed in this layer, each model can implement a different form of P2P energy trading [47].

The second dimension makes distinguishes between the size of the participants in the P2P system, i.e. premises, microgrids, cells, regions (consisting of multi-cells). An individual premise refers to a single house connected to the network.
Microgrids are controlled and coordinated electricity distribution networks containing loads and DERs, which can be connected to a central grid or work individually. Normally, a microgrid consists of a of collection individual premises and DERs in a geographically local area.
A cell is a concept that consists of multiple microgrids. It is used to define a wider area of network in

which DERs can be controlled in response to a number of objectives. Cells may contain multiple microgrids and can function connected to a main grid or individually. A cell, microgrid or a region can all be considered a peer and trade with each other [47].

The third dimensions shows the time sequence of the P2P energy trading process.
Bidding is the first process when energy customers (producers, consumers and prosumers) reach trading agreement with with each other before the second process, exchange of energy. In this process, energy is generated, transmitted and consumed. In the final process, the settlement, the bills and transactions are settled. If the seller can not deliver the sold amount or the buyer can not pay the bought amount of electricity, differences are settled in this process as well [47].

Before the system can work, the right type of technologies need to be identified and categorized.
Studies show that P2P energy trading is able to reduce the energy exchange between the community grid and the main grid. This is a positive movement towards independency of the main grid. P2P energy trading also helps to balance local generation and demand, and thus, has the potential to facilitate a large penetration of renewable energy resources in the power grid.
However, a series of reforms on the current energy policy, laws and energy trading systems are still required before it becomes a reality.

8 Investments

As can be seen in section 4.2.1, investment prices influence the pay-back time a lot. If the pay-back time is too long, a private might not be willing to invest. A subsidy from the government can help to convince people to make investments in renewable technologies. The large benefit this investment brings, is becoming independent of the main national grid if more people in the community are willing to make this investment. Together with consumers they can form a P2P grid. As can be seen in 11, in app C, the energy bill for the prosumer is lower than for a consumer. For a consumer, the bill is still lower than when the consumer is only consuming energy from the national grid.
The energy bill for a prosumer is lower than for a consumer, because a prosumer produces its own energy and only pays of its investment and a consumer still has to purchase it from a prosumer who prefers to pay of its investment quicker.
This can motivate more people to invest in becoming a prosumer. However, this creates a larger surplus in electricity. When there is a lot of something and the demand gets lower, the prices also drop. When the prices drop, prosumers might not have the profit anymore they used to have and selling it to the grid gets more profitable. This has the opposite effect of what is wanted to achieve, independency of the national grid. This implies that there is an optimum prosumer-consumer ratio, however, according to *Scott Kessler*[6]*, Director, Business Development of LO3 Energy* (Parent company of *Brooklyn Microgrid*, this optimum ratio is yet to be found.

Using the system implied in the *Brooklyn Microgrid*, where prosumers can set their minimum selling price and consumers their maximum purchase price. Trading is done anonymously and automatically with the price settings of the seller and buyer taken into account [48].

Vandebron has set up a network with the same idea as a P2P network. Consumers can buy directly from producers, such as farmers with wind turbines. *Vandebron* acts as the supplier and provides incentive tariffs for consumers and producers to exchange energy. If producers are in need of additional energy, they can buy it from *Vandebron* at a lower price [47]. This is not yet a fully P2P grid, because *Vandebron* acts as an intermediary. In a P2P grid, trading and transferring is done directly between producer and consumer. They are connected via the existing grid, but this grid is from network operators. If grid operators are not a part of the energy trading anymore, they can shut down the network and a new network has to be installed or the existing network needs to be bought from the operators. This increases the total investment that needs to be made in order to create a functioning P2P network.

The total investment of creating such a P2P system will be high. It consists of investing in renewable energy sources, possibly a new grid or otherwise renting/buying the existing one, a system that

[6] The question has been asked to him during an online meeting with other students.

keeps track of all energy and money flows and that arranges trading between producer and consumer. But also investments in order to quit the natural gas consumption need to be made in order to become sustainable. Using a different type of gas (e.g. hydrogen, biogas) has different properties than natural gas. This implies the requirement for new stoves in households, but also large burners in the industries need to be changed. If it is chosen to not use any gas anymore, the electricity consumption will increase drastically. To cope with this rise, a lot more renewable energy sources need to be installed.

For households, the transition is going to self-providing all-electric houses. This requires investments in heat pumps and renewable electricity sources such as solar panels or wind turbines. The amount of solar panels in the Netherlands, has increased drastically in the last couple of years. This is because the government has provided a subsidy that covers the V.A.T. of the installation. Also the subsidy in 2015 for heat pumps resulted in a rise of installations, as can be seen in the figure below. The blue line indicates the total newly installed heat pumps each year, the orange line the number of ground-water heat pumps and the grey line the air-water heat pumps [49].

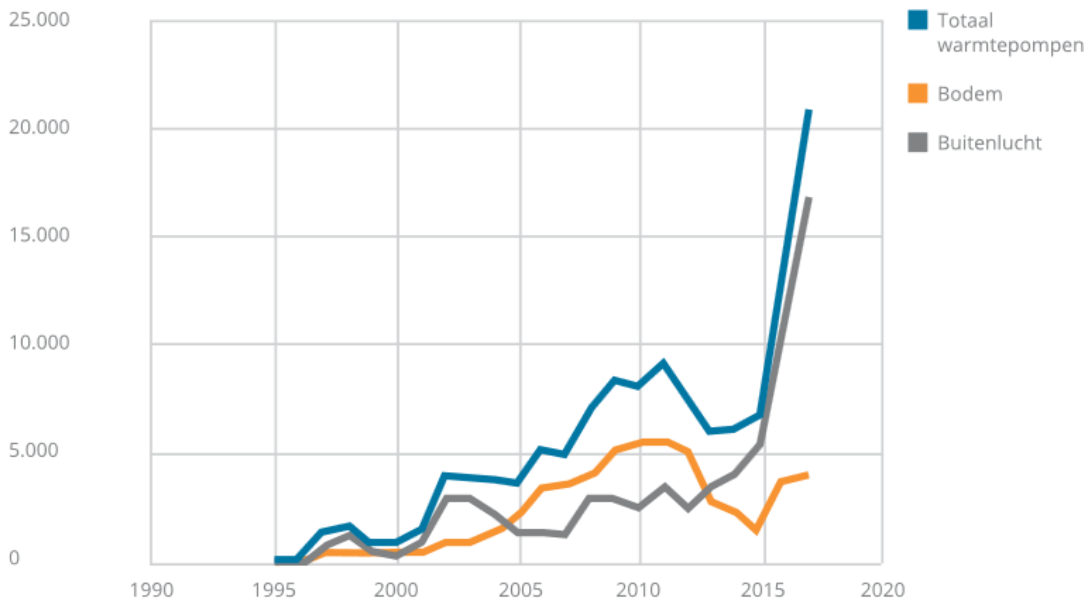

Figure 8: Growth in the number of newly installed heat pumps per year .

This shows how important it is that the government helps to stimulate the implementation of renewable and self-sufficient techniques. Now it has been done by giving subsidies, but applying loans without interest can also help to stimulate this transformation.

9 Stakeholder analysis

When a new type of energy network is being introduced, a lot of people and institutions are touched by this. New rules need to be made and a new network needs to be developed from scratch. Steering something new and big into the right directions, means a lot of parties need to work well together. Parties involving this energy network transition are given in the table below.

Stakeholder	**Interests**
Government, policy makers and regulators	Ensuring competition for affordable energy for end-users, sustainable energy supply, low carbon energy system, energy security
Communities/consumers	Reduction in costs from energy, emission reduction, energy independence, energy supply, security, resiliency
Households/prosumers	Use of local, affordable and clean energy at low costs, sale surplus and purchase deficit
Energy producer	Investment in energy system (maximize profit), sale local generation
Energy supplier	Profit from deficit energy supply, portfolio optimization, increasing renewables in portfolio, new roles and business models
Energy service companies (ESCOs)	Profit from energy efficiency, operation and management local generation, role in improvement of efficiency and operation and management of local generation
Technology providers	Sell technologies to transform the existing energy landscape both production and consumption, promotion of local generation and demand side management technologies
Aggregators	Business model for making profit, maximize value of flexibility in markets, role in making the system more efficient
Balance response parties	Portfolio optimization, balance energy procurement at lowest costs, provision of accurate scheduling to system operator
Transmission system operators (TSOs)	Maintain a larger system balance of supply and demand at lowest cost for the consumers, maintaining a larger system balance of demand and supply
Distribution systems operators (DSOs)	Distribute energy to neighbourhood with an affordable, safe and reliable grid, avoiding grid accumulation, defer network investment, self-balancing energy islands in smart grids
Software company	Developing software that monitors all electricity and cash flows

Table 21: Stakeholders and their interest in the system [7, p.12].

A producer is someone who owns a solar or wind field to provide additional electricity directly to the community grid without consumption.

		Influence	
		Low	**High**
Interest	**Low**	Aggregators, Balance response parties	Government, Energy producer and supplier, ESCOs, TSOs, DSOs
	High	Technology providers, Software company	Pro- and consumers

Table 22: Interest-influence matrix of the stakeholders mentioned in table 21.

Aggregators and balance response parties are stakeholders that will just be part of the system, but will not have influence or interests on the system. Technology providers and a software company have interests in a P2P system because of economic reasons. If there company is the one providing the technology/services they can earn money on that. But besides delivering the technology, they will not have any influence. The government, energy producer and supplier, ESCOs, TSOs and DSos all have influence on a P2P network. The government determines the legislation that has influence on the network. The energy producer and supplier have influence because they determine how much, if any, energy is going somewhere. The same holds for ESCOs, TSOs and DSOs. But because they have influence on the present network, they might not be interested in implementing a P2P network. Legislation has to be adjusted and companies can lose their influence in the new network. Pro- and consumers are the ones that obtain money-wise benefits from a P2P network and since they can set their own electricity prices, they also influence the flow of electricity.

The parties that supply the new technology and software play a major role in the transition to this new network type. Existing technologies need to be improved (e.g. solar panels, heat pumps, wind turbines, insulation for houses) and new technologies need to be developed (e.g. storage systems that are capable of storing, receiving and transferring the right amount of electricity whenever needed without delays). A new type of software needs to be developed through which consumers and prosumers can trade their energy for prices they can set themselves[7]. Privacy in the software is also an issue. It should be able to perform incognito trading between prosumers and consumers. But also the data storage should stay unavailable for third parties who want to use the trading data for their own benefits.

Everyone who has a large influence on the present energy network (e.g. by owning the distribution network), might lose this influence due to the consumer becoming becoming less dependent on the main network and more on the smaller microgrids. Consumers are depending more on the smaller microgrids than on the large main grid, because energy is produced locally and thus does not have to be transferred over large distances. Companies that arrange the transmission and distribution etc. can stay influential, but their business model has to change. Where they now focus on local transmission and national distribution, the focus should go more to distributed transmission and local distribution. They can also play an important role in maintaining the smaller microgrids instead of the larger main grid. Companies that maintain the large grid already have knowledge on that subject and can use that to maintain microgrids.

In the present energy situation, the government gets a lot of money from the natural gas production. This will cease inevitably. A new source of income will need to be found. This come in the form of V.A.T. on technologies that are implemented in the transition to a P2P network. Increasing costs for such a transition can push privates away from making these large investments. As can be seen in section 4.2.1 and 8, stimulating privates via subsidies helps to implement the new and renewable systems quicker.

[7]Brooklyn microgrid has already setup a version of such a mobile application[48].

10 Discussion

In the case study done in this paper, starting a P2P network for a 20 household sized community, a lot of assumptions have been made.
For example, all households are average households, which means, they all consume 2410m^3 natural gas and consist of 2.15 persons, which resulted in an assumed consumption of 3055 kWh on electricity. Also all houses have assumed to be detached. A 20 household large community of only detached houses can exist, so nothing is wrong with this assumption. The size of these households do not need to have an average of 2.15 persons. And even if this would be the case, they do not necessarily consume the national average amount of energy. Also the average household size now does not have to be the same as in 2050. This change will also need to be taken into account for more precise calculations.
Assumptions have also been made with respect to materials (solar panels, heat pumps etc.). The variety in the solar panel landscape is huge, hence choosing different type of panels, would have resulted in different results. The power production from solar is not the same each day in a single month. It can not be predicted how the solar radiation is each day especially not for a couple of weeks, let alone years into the future. hence, the real production can differ from the production assumed here.
Heat pumps have a SCOP, which is an average of their COP throughout the year, this is assumed to increase with 25% due to innovations and a better efficiency in the future. But it also depending on the outside temperature, which might not be the same anymore in 2050 due to climate change.
It has also been assumed that materialistic prices remain the same over time, this will not be the case due to inflation. This will affect the result in the future scenario. Operation and maintenance costs are not taken into account as well. If this would be done, the results would change as well.

The technologies used are existing and well functioning technologies. In the future, new and better technologies might exist. Such as PVT panels, which is a new technology that looks very promising. But first, more testing needs to be done before the new type (that can supply heat pumps at -10°C) can be used.
The same is for vanadium redox batteries. They look really promising, but are still very new and need to be improved and shrink in size in order to be able to use them in households. If the P2P storage systems would go to large local systems in a community, a vanadium redox battery might be suitable more quickly.

The list of energy storages mentioned in app. A.2 is large. But still not all types are covered. If other storage systems are taken into account as well, there might be a better system to use.
Solar panels are not the only way of producing renewable energy. Other renewable energy sources, such as vertical axis wind turbines (VAWTs) are also a good option to produce electricity. These can be made to any size in order to suit houses. It is chosen not to incorporate this in the paper because of time reasons. But for further research, implementing VAWTs to generate electricity is advised, because in the Netherlands there is plenty of wind throughout the year.

The results found in section 6, show that a 20 household large community with individual storages of 6.82 kWh - 15.15 kWh are already self-sufficient for 25% - 33%. Increasing this storage and the community will increase the self-sufficiency and decrease the annual energy costs.

If all stakeholders cooperate in forming a P2P network, the consequences of implementing it need to be studied as well. Introducing a P2P network also has the potential to change the behaviour of energy consumption of both the consumers and prosumers. For example, they will tend to consume more hot water when there is more electricity generated by their renewable sources. Those changes will further lead to conflicts between the economic performance and the social dissatisfaction.

11 Conclusion

Looking at the research question once more;
Which storage system is most suited on a technical and social level for local usage? And how will the implementation of an ICES affect the community?

The storage system that turned out to be suited the most is the lithium-ion battery. This battery has a high energy density, allowing it to fit in a house and has the right properties in order to secure the energy demand.

Each scenario studied has its own consumption and production, thus is in need of a different storage capacity. Based on figure 6, the first scenario, where gas is still used, has the least advantage of a P2P network of 20 households. Its self-sufficiency is the lowest and its electricity prices is the highest when compared to the other scenarios.
Future scenarios have a lower capacity than the present day all electric scenarios. This is due to the lower consumption of the households in the future scenario.
The best present day scenario is in combination with an air-water heat pump, which results in a self-sufficiency of ∼33% and and annual electricity bill of ∼375£. The future scenarios are just a bit below the self-sufficiency percentage and just above the annual electricity price.

Making houses renewable helps in creating a self-sufficient community. But how self-sufficient they become depends on the size of the community and the storage capacity available.

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Appendices

A Batteries

A.1 Battery characteristics

1. **Discharge power**: rate at which energy can be removed from storage per unit of time [10].
2. **Charge power**: rate at which energy can be placed into the storage per unit of time [10].
3. **Energy storage capacity**: Amount of energy that can be held in a storage system [10].
4. **Discharge time**: time that indicates how long a storage system can provide energy at maximum power level [10].
5. **Charge time**: time that indicates how long it takes to completely refill the storage system at maximum charge power [10].
6. **Operational time**: time that indicates for how long a storage system can be expected to provide an average discharge power. (Always discharging at maximum discharge power might not always be desirable)[10].
7. **Energy density**: the amount of energy stored in a given system per unit volume [10].
8. **Discharge response time**: time that indicates how long it takes before the requested amount of energy is provided by the storage system [10].
9. **Charge response time**: time that indicates how long it takes to deliver energy into a storage system after the delivery request [10].
10. **Energy carrier**: the form which energy takes when extracted from the storage (e.g. gas, electricity, heat) [10].
11. **Costs**: evaluated in terms of costs per power and in terms of costs per unit stored energy capacity [10].
12. **Ramp up/Ramp down speed**: capability of a storage system to increase or decrease its power output over a period of time [10].
13. **Self-discharge rate**: amount of energy in a storage system that is lost (unintended discharge) per unit time [10].
14. **Round trip efficiency**: Percentage of energy lost after extraction compared to what has been put into the storage system [10].
15. **Lifetime**: time that indicates how long a system is expected to last [10].
16. **Storage time**: time that indicates how long energy is typically stored [10].

A.2 Battery types

1. **Pumped hydro storage** - Mechanical storage: pumped hydro storage uses a upper and lower reservoir to generate hydro electricity. When there is a surplus in electricity, water can be transferred from the lower reservoir to the upper reservoir using a pump. When electricity is needed, water is released from the upper reservoir to generate electricity using turbines [11].
2. **Compressed air energy storage (CAES)** - Mechanical storage: underground caverns are used to store compressed air using surplus electricity. To produce electricity, this compressed air is released and passed through a conventional gas turbine [11].
3. **Flywheel** - Mechanical storage: a rotating mass connected to the electricity grid via a generator which generates electricity by rotation [11].

4. **Supercapacitors** - Electrical storage: electricity is stored in large electrostatic fields between two conductive plates. By releasing the stored electricity, a lot of power can be released near instantaneously [11].

5. **Superconducting magnetic energy storage (SMES)** - Magnetic storage: flowing electric current is stored in a superconducting coil [11].

6. **Lead acid batteries** - Electrochemical storage: electricity is stored by charging an electrochemical cell composed of a metallic lead anode, a lead-dioxide cathode and an electrolyte from a sulfuric acid solution [11].

7. **Lithium ion battery** - Electrochemical storage: electricity is stored by charging an electrochemical cell composed of a graphite cathode and lithium metal anode [11].

8. **Vanadium redox flow battery** - Electrochemical storage: a reversible fuel cell is employed by flow batteries. The fuel cell has electro-active components dissolved in an electrolyte. This allows the decoupling of power and energy ratings, which allow power output and energy storage capacity to be completely independent [11].

9. **Hydrogen gas storage** - Surplus electricity can be stored in the form of hydrogen gas using electrolysis of water. Hydrogen can be stored in and extracted from appropriate facilities (e.g. salt caverns, surfaced containers or gas grids). Hydrogen can be fed into a fuel cell or combusted to provide a combination of heat and electricity [11].

10. **Salt caverns (methane storage)** - Salt caverns can be used as gas storage facilities which typically have less working volume than larger aquifers and depleted gas/oil fields [11].

11. **Aquifers & depleted gas/oil fields (methane storage)** - Aquifers and depleted gas/oil fields are used for seasonal gas storage or as a strategic stock to support low levels of natural gas production [11].

12. **(Liquified) Natural gas storage** - Storing liquefied natural gas requires additional processes with respect to storing gas. To be able to store liquefied gas, the gas needs to be stored under high pressure and low temperatures [11].

13. **Hot water (sensible Heat)** - Thermal storage: energy is stored by heating water in a insulated tank. This energy can then be used for heating [11].

14. **Underground Thermal Storage (UTS) (Sensible Heat)** - Thermal storage: energy is stored by pumping water underground to into porous rock or an aquifer. Cold water can be heated on cold days and warm water can be cooled on warm days [11].

15. **Latent Heat (Phase Change Materials)** - Thermal storage: environmental heat is used allow phase changes in materials. The heat is released or absorbed depending on the phase change [11].

16. **Molten Salts (Sensible Heat)** - Thermal storage: salt is heated using solar energy by focusing the energy on the salt with the use mirrors. The molten salt will generate electricity via a steam generator and the cooled salt can be reheated. Using salt, solar energy can be used to generate electricity all day long. This is due to the high heat capacities of molten salts [11].

B Electricity consumption in June

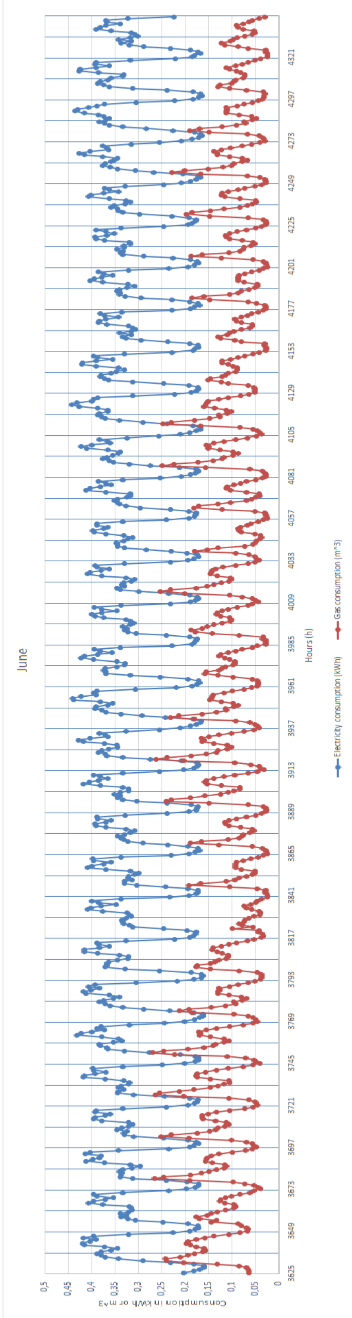

Figure 9: Hourly consumption in the month June for a house with a yearly consumption of 3055 kWh.

The gas (red) peaks are just before noon and the electricity (blue) peaks just after that.

C Performance comparison between P2P and P2G

Metric	Method	Battery, kWh	Summer	Spring/Autumn	Winter	Annual average
Self-consumption, %	P2G	0	23.9	22.8	24.1	23.4
		4	48.4	52.3	54.9	52.0
		8	65.8	74.3	79.3	73.4
		12	80.7	88.6	94.3	88.1
		16	90.7	96.4	99.5	95.8
	P2P	0	66.0	62.9	66.9	64.7
		4	86.5	87.7	96.6	89.6
		8	97.2	99.6	100	99.1
		12	100	100	100	100
		16	100	100	100	100
Self-sufficiency, %	P2G	0	15.1	9.5	8.7	10.7
		4	27.1	19.2	17.7	20.8
		8	32.8	26.0	24.2	27.2
		12	35.2	29.4	27.3	30.4
		16	35.8	30.4	27.8	31.1
	P2P	0	45.8	32.3	24.2	33.7
		4	56.5	41.7	32.4	43.1
		8	63.3	46.7	32.8	47.4
		12	63.3	46.7	32.8	47.4
		16	63.3	46.7	32.8	47.4
Average energy cost per household (£/day for each season, £/year for annual)	P2G	0	1.41	1.52	1.67	558.85
		4	1.25	1.38	1.55	507.94
		8	1.18	1.28	1.45	473.30
		12	1.15	1.22	1.40	456.61
		16	1.16	1.22	1.40	456.41
	P2P	0	0.89	1.13	1.34	409.63
		4	0.67	0.93	1.14	334.63
		8	0.53	0.82	1.13	301.50
		12	0.53	0.82	1.13	301.50
		16	0.53	0.82	1.13	301.50

Figure 10: Comparison of the seasonal and yearly performance of a P2P and a P2G [46, p.272]

The results for the P2G energy trading are considered as the base case for the comparison purposes. Both the charging and discharging efficiency was 90%. The price of the energy bought from the grid was taken as 15 pence/kWh and the price at which energy is sold to the grid was 5/per kWh [46].

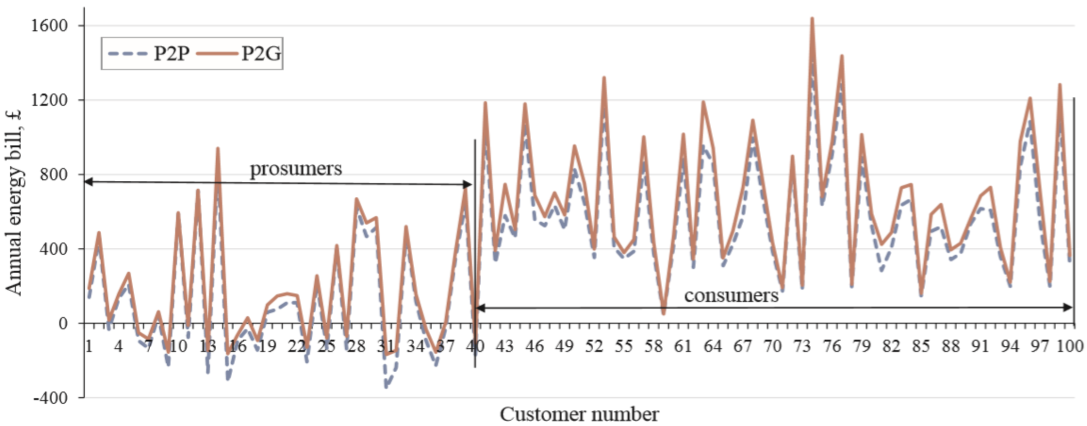

Figure 11: Electricity bill for individual customers in a P2P and a P2G network.