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Executive Summary

Deliverable 5.2 finalises the investigations into the techno-economic feasibility of a smart grid and local E-Car concept for the Dutch Demonstrators in the SERENE project. Based on our prior theoretical investigations reported in D5.1 (technical); and D3.1, D3.2, D3.3 (Social innovation and socio-economic) this report proposes various scenarios liable to be green Business Models for the Dutch demonstrators. This achieves the first target of WP5: “investigate 100% local renewable and balanced energy supply …” and also makes progress on the second target “Develop, test and analyse a local smart grid to soft-island neighbourhoods”, since technical designs are continuously being developed, tested and analysed via the monitoring systems installed and controllable/flexible assets studied. The applied-framework and scenario considerations evaluate flexibility and energy billing options for improving the financial outcome for the local energy community. The report further details the specific set of measures proposed in D5.1 and their potential for the value created within the boundaries of realistic conditions of implementation.

Deliverable 5.2 is one of the first reports that studies a business model of the SERENE project and links it to the technical and implementation aspects of the Dutch Demonstrator. Based on previously presented technical designs and improvements, this techno-economic study focuses on conditions for implementation and feasible business cases within the demonstration sites; namely: flexibility, energy costs, energy storage, renewable energy usage, EV charging, yearly energy billing of end users, considering technical and economic feasibility and applicability. The main subjects of the study are the two local energy communities Vriendenerf and Aardehuizen in Olst (NL); with a focus on the latter. Nevertheless, the analysis encompasses all involved stakeholders (DSOs, spin offs, energy/flexibility/e-mobility) and aims to deliver broader benefits of the society[1].

The financial and business case potentials are analysed for individual households, communities, and solar charged e-mobility. Different potentials for avoiding costs in the various scenarios are indicated. The maximum financial revenue potentials are considered by estimating electricity billings for individual houses, solar carpark and the whole community. The benefits of smart home energy management systems are quantified. This contributes to the further analysis of economic feasibility and ecological sustainability as well as sensitivity analyses.

This report captures the possibilities for smart energy communities contributing to the green energy transition with new viable business cases, producing and consuming locally is seen as a great source of avoided costs against increased energy prices.

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[1] Societal aspects, governance and social innovations, its results and business models as a framework (in its full extent applicable for three demonstrators) will be detailed further in WP3 - D3.4. This report will focus on the Dutch demonstrator.

1 Introduction

1.1 General introduction

Ambitions of a sustainable village or a local energy community are certainly the starting point, yet feasibility, from both a technical and economic perspective is crucial for their continuity. Local energy communities will create monetary and technical value with their flexibility. Practical data, recent energy prices and results of our prior investigations of D5.1 show us that some flexible assets have a greater potential, therefore can create large cost savings as well as greater improvements to the reduction of the environmental footprint. To quantify those impacts and coordinate them into a set of long-term solutions, a business model framework is proposed by the Business model research group of Saxion University[1] (see Figure 1). One will notice that the business models are broad and interdisciplinary. The framework is applied in the context of techno-economic study (Figure 2).

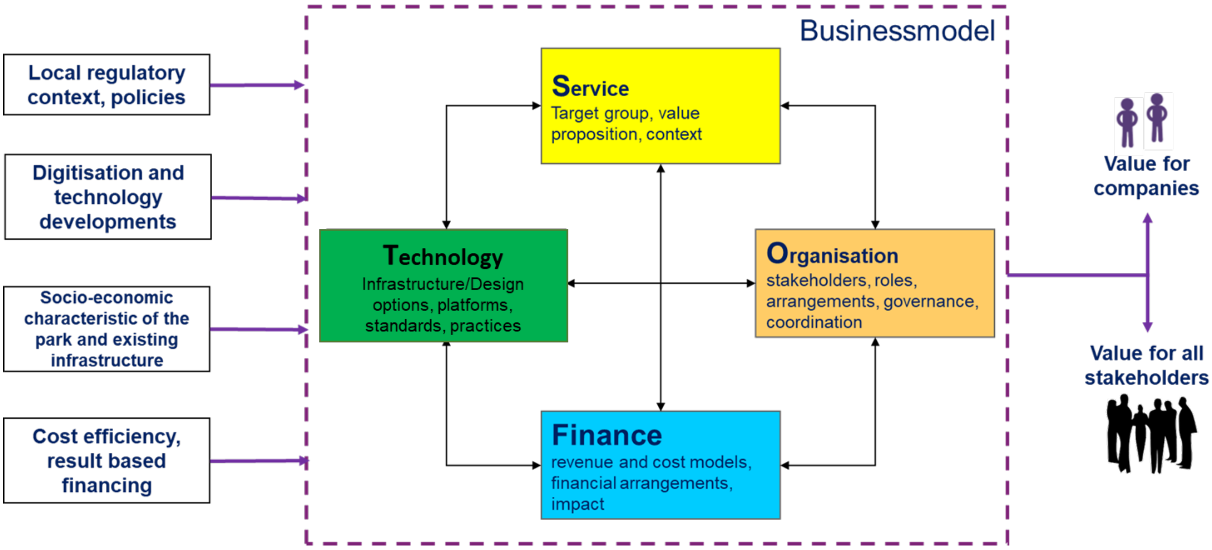


Figure 1. Business model framework [1]

This report starts with this brief introduction and scope (Chapter 2), followed by business cases for neighbourhoods and e mobility (Chapter 3), technical designs (Chapter 4), conditions for implementations (Chapter 5), business models and flexibility value creation for all stakeholders (Chapter 6), and last but not least, discussions, conclusion and recommendations (Chapter 7 and 8) (Figure 2).

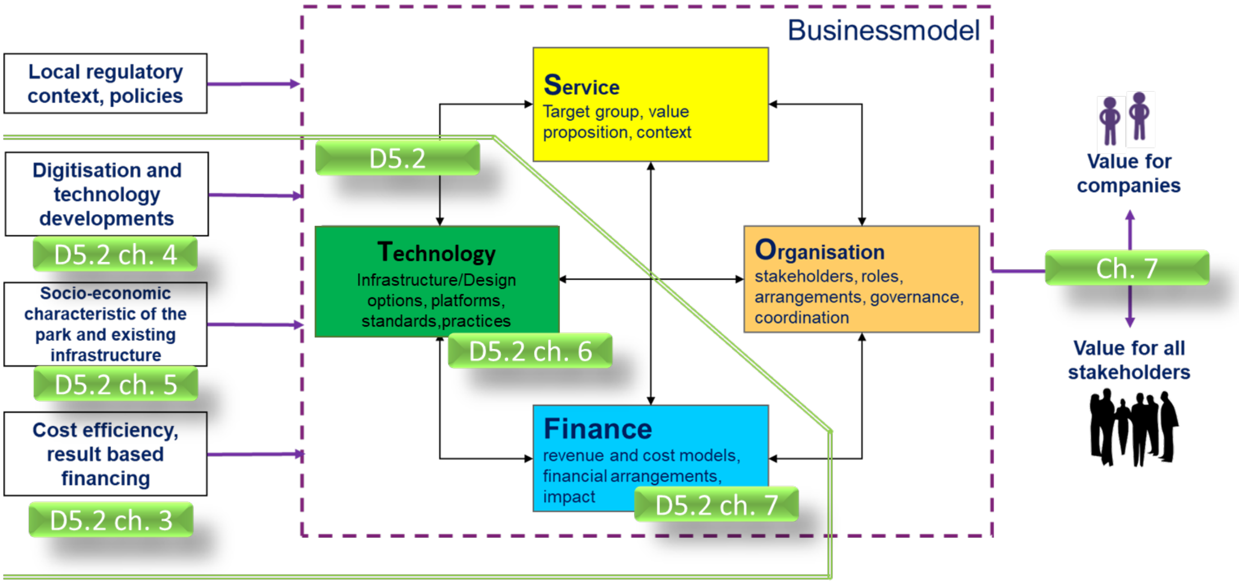


Figure 2. Business model framework used for the techno-economical study conducted, green quadrant represents the focus linking the chapters of the report

1.2 Sustainability goals of the communities from techno-economic perspective

Because of their dedication to sustainability, the communities of Vriendenerf [2] and Aardehuizen [3] are enthusiasts for:

- Environmental friendliness
- Sharing their energy between the residents of the community
- Storing their energy to avoid the using energy from grid (due to fossil fuel mix in grid)
- Sharing their surplus energy with the neighbourhoods of Olst (local)
- Sharing their knowledge and experiences to help others being sustainable
- Helping and promoting other sustainable communities to emerge

In general, both communities would like a small monetary return to sustain their community which is detailed in Ch.3. To indicate their level of motivation, some participants even claim to be ready to make sustainability efforts even if there is no economic incentive or even a slight negative incentive, albeit temporarily. However, significant long-term losses are not an option: they wish to sustain their communities and apply smart technologies that will benefit both them and the society economically and ecologically. The communities consist of individuals and therefore some of the above claims will be crosschecked by WP3 surveys and questionnaires. Nevertheless, the participants are active, support the energy transition of the neighbourhoods of Olst, cooperate with tiny houses that have been built recently, are active in the energy cooperation of Olst and are closely cooperating with the municipality.

Both communities only have an electricity network, are not connected to the gas network and are trying to avoid as much as possible, fossil fuel-based energy. They are heating their houses and hot water with electricity (ground source heat pumps, in the case of Vriendenerf), solar thermal collectors+ e-boilers (Aardehuizen) and wood stoves (refer to D5.1 for further heating schematics and details). In this report, we investigate how, under which conditions and with the help of renewables and flexible assets, the feasibility of the smart grid feasibility can be achieved.

1.3 Research aims

The main research question:

- How can current electricity bills and the sustainability and resilience of the inhabitants of Dutch residential energy communities be improved by implementing technologies or different billing methods, as well as different forms of business models?

Figure 3 gives an overview of the problematics and scenarios analysed in this report:

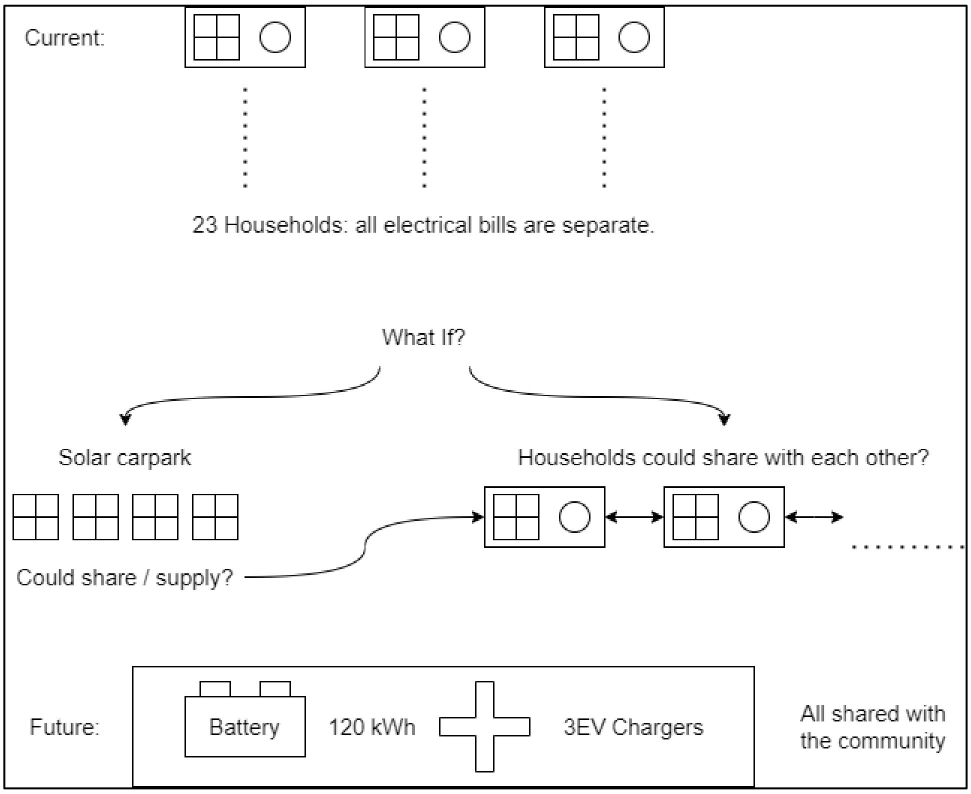


Figure 3. Techno-economic feasibility analysis on: current scenario; possible scenarios if contractually allowed; with current infrastructure and future scenarios with the ongoing installation of the equipment's.

Some regulations and aspects of the current market structure currently limit Dutch residential energy communities. To provide the full picture, here is a list of related sub questions:

- What are the possibilities to share the overproduction of energy from the solar carpark among the inhabitants?
- What are the possibilities to share the overproduction of electricity between all the households?
- What are the added values of e-mobility?
- What are the added values of different electricity pricing?
- What is the value of a smart grid, energy management system and optimisation algorithms?
- How do the future technologies and policies affect the Aardehuizen?
- What are the technical designs that suits the setup and are future proof for the Dutch residential sector?
- What are the conditions for implementation of certain technologies?

These questions will be addressed according to the steps summarised in Figure 3.

1.4 Business model scope

The previous social innovation studies conducted by WP3 depicted the contexts, factors, and barriers. As depicted in Figure 2, this report will focus more on technology, finances, digitalization, technology development, existing infrastructure, cost and efficiencies and will depict the corresponding outcomes. The energy in the built environment is categorized based on four main aspects: energy supply, energy demand, storage and integration aspects (Figure 3). All of four areas are discussed from a techno-economic perspective in this report.

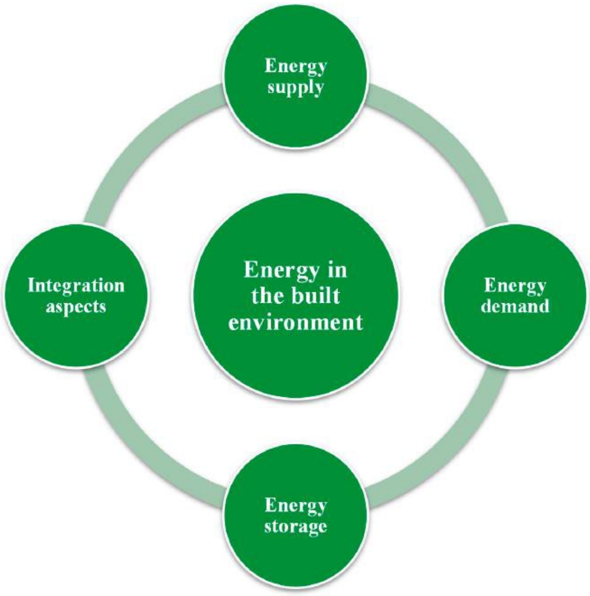


Figure 4. The main four areas of energy in the built environment context [4]

The report and its findings are based on the techno-economic revenue/cost models, to add up different electricity billing methods and return of investment of the assets. The communities that are part of the Dutch demonstrators do not use natural gas but use biomass and solar thermal enhanced e-boilers, which is a good base for comparison to understand avoided costs and their thermal consumptions. We will also detail those boilers in technical designs. The conditions of implementations as depicted in chapter 3, are also considered in the modelling and analysis of the energy bills.

2 Business case: feasibility and potentials for current state of the Dutch demonstrators

Access to electricity is considered a citizen right in the Netherlands. Yet, geopolitical changes have made a significant impact on an essential good as energy. According to Milieu Centraal (initiated by Dutch ministry of the Environment), an average Dutch household is prognosed to consume 2479 kWh and 1169 m^3 gas; and if this household had in beginning 2021 a yearly basis fixed contract, it would actually have 1260 € of an annual energy bill [5]. The fixed contracts are rare since the energy crisis in the European union, and if the same contract started at the beginning of January 2022, this would be 2800€ [5]. And if a new contract was to be made in Netherlands in August 2022, our market analysis for these prices are between 4600- 6700€ for an average Dutch household all-inclusive [6],[7],[8]. The price of the electricity more than doubled for end users and not per se related to increased margins in electricity [9]. There were some bankrupted energy suppliers, who could not anticipate and resiliently respond to changes in prices due to their high amount of fixed contracts, while variable contract is dominant and fixed contracts are not proposed anymore by Dutch energy suppliers. Keeping those events in mind for Dutch electricity market, this chapter will explore what will be the effects on the price of electricity for the community of Aardehuizen. Different electricity billing schemes will be explored to indicate what choices will benefit the energy communities and quantify the benefits and indicate situational dependencies. First of all, the current electricity billing system and Dutch conditions will be detailed. Thereafter, we will compare different energy tariffs for Aardehuizen inhabitants and how much do they benefit in terms of peak reduction, CO_2 emissions and costs by exchanging energy with each other, being equipped with smart energy management systems (current scenario with optimisation), and investing in storage technology and e-mobility (future scenario).

Geopolitical changes, climate events or situational changes could make the energy prices better or worse, so a sensitivity analysis is also proposed by suggesting different prices, rather the price in 2021 or 2022, but also different scenarios such as public EV charging. It will help with forecasting the future scenarios of the Aardehuizen.

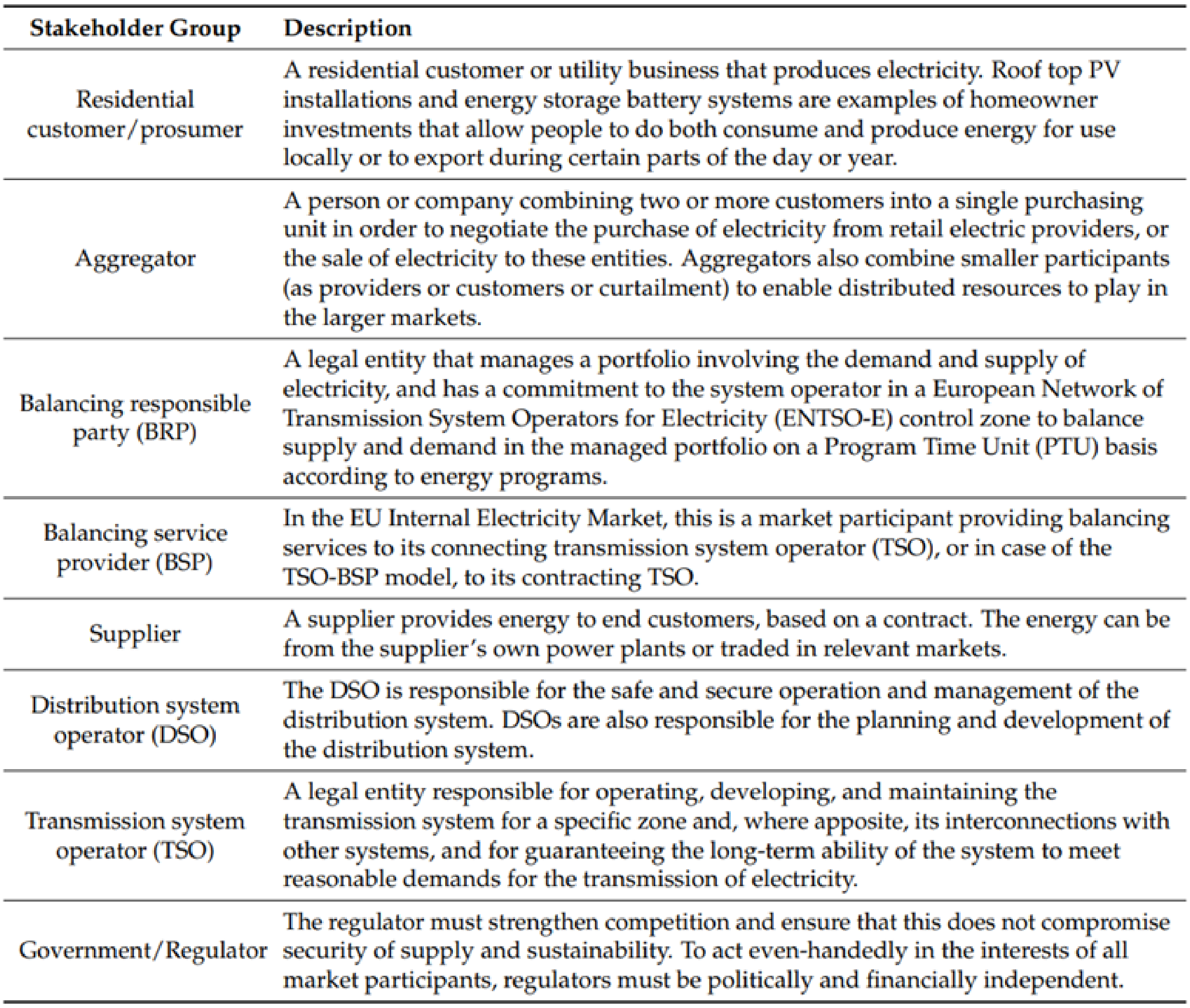
2.1 Stakeholders

Table 1 is defining who are the main stakeholders in the electricity network in general and describes them.

Table 2 defines the network operators for the Dutch case. Tennet is the only TSO for electricity, and Enexis is the second largest Dutch DSO and responsible for the area of the pilots locations, Olst, The Netherlands [10].

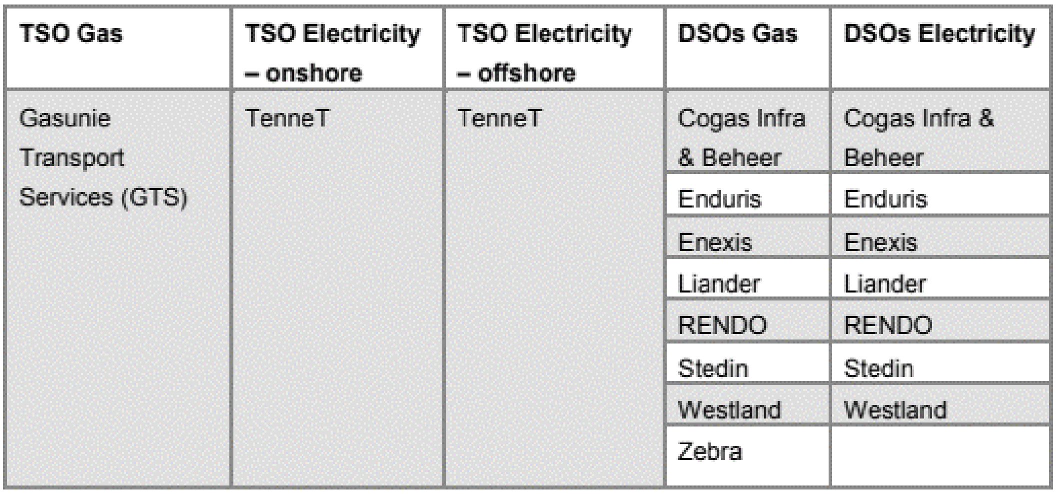
Enexis, Liander and Stedin constitute 94% of the whole of the Netherlands DSO electricity market [11]. Therefore, we will mainly consider their policy of working, although it will of course reflect the current laws, ACM, and other Dutch regulatory institutes.

Table 1. Stakeholders in smart grids environments and descriptions of their roles [12]



Stakeholder Group	Description
Residential customer/prosumer	A residential customer or utility business that produces electricity. Roof top PV installations and energy storage battery systems are examples of homeowner investments that allow people to do both consume and produce energy for use locally or to export during certain parts of the day or year.
Aggregator	A person or company combining two or more customers into a single purchasing unit in order to negotiate the purchase of electricity from retail electric providers, or the sale of electricity to these entities. Aggregators also combine smaller participants (as providers or customers or curtailment) to enable distributed resources to play in the larger markets.
Balancing responsible party (BRP)	A legal entity that manages a portfolio involving the demand and supply of electricity, and has a commitment to the system operator in a European Network of Transmission System Operators for Electricity (ENTSO-E) control zone to balance supply and demand in the managed portfolio on a Program Time Unit (PTU) basis according to energy programs.
Balancing service provider (BSP)	In the EU Internal Electricity Market, this is a market participant providing balancing services to its connecting transmission system operator (TSO), or in case of the TSO-BSP model, to its contracting TSO.
Supplier	A supplier provides energy to end customers, based on a contract. The energy can be from the supplier's own power plants or traded in relevant markets.
Distribution system operator (DSO)	The DSO is responsible for the safe and secure operation and management of the distribution system. DSOs are also responsible for the planning and development of the distribution system.
Transmission system operator (TSO)	A legal entity responsible for operating, developing, and maintaining the transmission system for a specific zone and, where apposite, its interconnections with other systems, and for guaranteeing the long-term ability of the system to meet reasonable demands for the transmission of electricity.
Government/Regulator	The regulator must strengthen competition and ensure that this does not compromise security of supply and sustainability. To act even-handedly in the interests of all market participants, regulators must be politically and financially independent.

Table 2. Network operators in the Netherland [11]



TSO Gas	TSO Electricity – onshore	TSO Electricity – offshore	DSOs Gas	DSOs Electricity
Gasunie Transport Services (GTS)	TenneT	TenneT	Cogas Infra & Beheer	Cogas Infra & Beheer
			Enduris	Enduris
			Enexis	Enexis
			Liander	Liander
			RENDO	RENDO
			Stedin	Stedin
			Westland	Westland
			Zebra	

2.2 Dutch residential energy contracts and price components

Three types of consumer contracts for electricity supply from the grid, are proposed by Dutch energy suppliers: fixed term, variable, and dynamic. These are explained below.

Fixed-term energy contract, an energy price is agreed upon for the entire duration of the contract (1 year or maximum 5 year). The increase or decrease of the energy price will not be reflected in the electricity bill. Profit margin and risk premium will be paid to the supplier. There is a cancellation penalty if consumer would like to end the contract prematurely. Since 2022, it is rare to find any fixed energy contract energy suppliers due to market risks and monthly changing energy process.

Variable energy contract is an agreement for an indefinite period. The contract continues, but you can cancel it monthly. The rate for a variable contract is a fixed rate for 6 months that the supplier usually adjusts on January 1 and July 1. Since the energy crisis of 2022, however, more and more suppliers are changing their variable rates more often, even monthly. Increase of energy prices are certainly reflected on the bills. Profit margin and risk premium will be paid to the supplier.

Dynamic energy contract is also an agreement for an indefinite period, it can be terminated per month, and it works with hourly prices. The rates for a dynamic contract differ per hour and depend on the demand (consumption) and supply (generation and production) of energy. You usually pay the basic purchase price at the time of consumption, but that does not apply to all providers of dynamic energy rates. These energy contracts are also referred to as a flexible energy contract. The simulations explained in section 4.1 are based on these hourly (day-ahead) prices for cost optimisation.

To start with more traditional and less complex, the fixed term energy contract was the main household level costumer contract in the Netherlands and still is in many countries. Apart from fixed term, or variable energy contract, there are fixed expenses per year (grid connection costs etc.) and per kWh (fixed for fixed term energy contract, variable per six months or even monthly). The pricing has different components, related to energy costs for the supply of electricity per kWh (energy supplier), energy taxes per kWh and yearly basis government incentives, as well as yearly grid fees (DSO and TSO). As mentioned, for variable energy contract, which is now the main contract by energy suppliers, beginning of the year and July are often the moments that prices are defined. That is why we will report those moments. According to the central statistical office of the Netherlands, Table 3 indicates different components of the electricity prices for an average consumer for a fixed or variable tariff (household).

Table 3. Electricity price components and average consumer prices according to CBS, 2022 [13]

Item	Explanation	January 2021	July 2021	January 2022	July 2022
Transport rate	Average amount that the consumer pays the grid operator per year for the transmission of electricity or gas. The actual amount depends on the region. (As detailed in Table 2)	257.36 €/year	257.36 €/year	267.12 €/year	240.63 €/year
Fixed delivery rate	Average amount that the consumer pays per year in fixed costs for the supply of electricity or gas (also called standing charge) when concluding a new contract. The actual amount of this amount per household depends on the type of contract, the duration of the contract and the supplier with which the consumer enters this contract.	71.33 €/year	73.26 €/year	72.55 €/year	65.36 €/year
Variable delivery rate	Average rate that the consumer pays per kilowatt hour in variable costs for the supply of electricity when concluding a new contract. The actual amount of this amount per household depends on the type of contract, the duration of the contract and the supplier with which the consumer enters this contract.	0.0697 €/kWh	0.0928 €/kWh	0.3169 €/kWh	0.5028 €/kWh
Storage of sustainable energy (ODE)	A levy on the consumption of electricity and natural gas to finance the promotion of renewable energy production. Decided in the Sustainable Energy and Climate Transition Storage Act.	0.0363 €/kWh	0.363 €/kWh	0.369 €/kWh	0.033 €/kWh
Energy tax	Tax on the consumption of electricity and natural gas. This is decided in the Environmental Taxes Act.	0.11408 €/kWh	0.11408 €/kWh	0.044 €/kWh	0.04 €/kWh
Energy tax refund	A reduction applies to the energy tax (also known as a tax credit). This is paid per electricity connection, independent if the tax paid is lower than this sum, as a basic right to electricity access by the citizens. This is decided in the Environmental Taxes Act.	-558.56 €/year	-558.56 €/year	-824.7 €/year	-742.98 €/year

The average price of variable delivery rate – cost for the supply of electricity five folded between July 2021 and July 2022. To refrain the impact of the price in overall inflation, the Dutch government hasn't only decreased the energy tax per kWh, but has also given incentives via Energy tax refund. Since 2019 from around -300€, the refund was increased to -558€ in 2021, and additional another supplementary -200€ to cover the expenses of the cost for the supply of electricity, rounding around -743€.

A similar assessment as table 3 could be made for natural gas, which is the main source for the heat demand of households. However, the households of the demonstration sites in Olst are not using natural gas for heating. Hence, we will not work this out in this report, except for Table 4, to make a valid comparison.

2.3 Average Dutch energy bill and solar payback times

Table 4 illustrates how the average household energy consumption reacted to those price changes. These average numbers in have been also verified by different suppliers, and the result is that under current conditions, the energy bill is easily approaching 4 k€. The biomass consumption is translated into natural gas equivalent, just to give an idea about the avoided costs. The financial consequences of solar thermal installations on the energy bill are also ignored since we are missing data.

Table 4. Dutch average energy bill compared to Aardehuizen. Avoided costs of solar energy for an average household based on simulation results without smart control

Yearly energy bill	**Dutch average household**			**Aardehuizen without PV***			**Aardehuizen with PV (5.65 kWp per house)**	
	2479 kWh	1169 m^3 gas	total after tax reduction	3851 kWh	632 m^3 gas eq.*	total after tax reduction	**With PV and net metering**	**PV Payback time (1.4€/Wp)**
Jan-21	644	1100	1,200 €	924	594	968 €	-500	5 years
Jan-22	1330	2300	2,800 €	2195.07	1245.04	2600 €	-553	2.5 years

*Based on energy consumption obtained through energy bills from 2016, further details refer to D5.1 (gas eq. deducted from biomass consumption)

Considering all these costs that are avoided, Aardehuizen, or any household with a similar consumption profile, could payback their rooftop solar panels (assumed to be installed 1.4 €/kWp) in 2.5 years. That is thanks to fixed / variable contract and net metering advantages that comes with it, and the tax reduction that is subtracted from the energy bill regardless every year.

Besides the energy tax refund, to keep the motivations of citizens to install rooftop PV panels and accelerate energy transition, the net metering (Dutch: salderingregeling) is also extended to continue until 2025. This regulation evaluates metering balance on a yearly basis, regardless of whether the delivered power is self-consumed or exported to the grid. The total import kWh minus the total export kWh over the year will be the basis of the electricity bill that a person needs to pay to their electricity supplier. With such high electricity prices, being energy plus household brings tremendous advantages. Yet, the energy that remains as surplus, will be bought back from the grid, depending on the energy supplier, estimated 9c€/kWh by authorities [14]. This number can be a bit higher depending on the energy supplier and their green labelling market, as such it could be found that until 2023 some suppliers propose 16.8 c€/kWh, therefore the supply numbers are quite conservative [15]. Sub - section 3.5 will also talk about the phasing out of net metering.

2.4 Current electricity bills of Olst

This subsection focuses only on the financial results of non-optimisation or an optimisation. The costs are calculated according to pricing components and three pricing schemes explained in section 3.2. The inventory of the energy consumption on a yearly basis was not available for Vriendenerf to conduct this study, therefore all the results below are indicating Aardehuizen (except one household in Vriendenerf explained separately in subsection 3.4.1). The nature of the scenarios investigated, and arguments leading to their selection, are summarized in the beginning of each subsection.

2.4.1 Individual households' current electricity bills

Fixed and variable pricing through an energy supplier are the two forms of energy contracts that exist in the neighbourhoods of Aardehuizen and Vriendenerf at this moment. No control is yet involved. In order to analyse the situation, every household was represented within an artificial load profile generator (ALPG) considering the composition of the household and technical variabilities, adding up to their yearly electricity bill. The profiles have been checked with real electricity bills of one inhabitant, and the real profiles deviate from the modelled profiles with around 10%. The difference is caused by behavioural variability of individuals. The worst case represented 15% more consumption than average, but this household doesn't have any rooftop PV. The best case household has a 7.5 kWp installed rooftop PV capacity, showing 10% less consumption than the average. The average case has a rooftop PV installation of 5.6 kWp.

Table 5 and Table 6 indicate the pricing estimations for 2021 and 2022 respectively, with relatively recent data of Aardehuizen and Vriendenerf.

Table 5. Year 2021, estimation yearly electricity bill per household (inclusive grid costs, energy services and taxes)

Type of contract	Scenario Case	Costs based on consumption	PV supply revenue (9c€/ kWh)	Net metered yearly electricity bill
Fixed **(25 c€/kWh)**	**Worst**	1000 €	N.A.	770
	Average	809 €	-373 €	-317 €
	Best	770 €	-685.5 €	-643 €

Vriendenerf -Fixed		974 €	-625€	-545 €
Variable	**Worst**	1013 €	N.A.	784 €
	Average	820 €	-373 €	-317 €
	Best	782 €	-685.5 €	-643 €

Table 6. Year 2022, estimated yearly electricity bill per household (inclusive grid costs, energy services and taxes)

Type of contract	**Scenario Case**	**Costs of electricity**	**PV supply revenue (9c€/ kWh)**	**Net metered yearly electricity bill**
Fixed (65 c€/kWh)	**Worst**	2535 €	NA	2098 €
	Average	2053 €	-373 €	-526 €
	Best	1955 €	-685 €	-851 €
Vriendenerf – Fixed		2553 €	-625 €	-754 €
Variable*	**Worst**	2314	N.A.	1877 €
	Average	1875	-373 €	-317 €
	Best	782	-685.5 €	-643 €

*Variable prices monthly applied from CBS database until September, prices of October until December are assumed to be 70 c€/kWh, as assigned as max limit by the Dutch government [13], [16], [17]

As you can see from the tables, the difference between years is striking for "non-PV", which is the worst case. The difference between a household sufficiently equipped with PV and another that it is not has a difference of a 1500 € a year for 2021 in the best case scenario, and this is expected to double this year.

Net metering has a lot of advantages, while a lot of costs are avoided to prosumers. Yet if the community could find a way, instead of selling this surplus back to the grid, and they agree on self-consuming within the neighbourhood, it could benefit both the consumer end user and the prosumer. That would allow consumers to negotiate with other individuals to pay less and prosumers to earn more with their yearly surplus. Although the numbers indicate 2.5 k€ potential, the net metering will phase out in 2025 gradually which needs to be considered further.

Due to the present high market prices for energy as a result of the Ukraine war and sanctions, the Dutch government introduces a temporary measure to put a cap on consumer energy prices up to certain consumption limits [18]. In this way, consumption reduction is still beneficial. Yet, price caps will have no influence for energy plus individuals or communities, which can be regarded as a missed opportunity to promote innovation. Aardehuizen and Vriendenerf are both energy plus, and independent from gas, which makes them now enable to help others if legal restraints would not be present.

2.4.2 Aardehuizen solar carpark current electricity bills and potentials

Currently, the solar park is one entity "behind the electricity meter" and has a large amount of over-production. On the same connection, there is only one non-controllable EV charger. The charging data is not available, but the energy production and consumption ratio (by the electric car) is estimated at around 4% based on findings by [19]. At this stage, this consumption is neglected and will be investigated further in future cases. The solar carpark does not benefit from net-metering, but benefits from another subsidy (SDE+), so there is a different pricing mechanism. In Table 7, the expected outcome is listed, regardless of a fixed or variable contract:

Table 7. Potentials of the solar carpark

Price assumptions	expected surplus price (9c€/kWh)	favorable surplus price (16.8c€/kWh)	If sold with 2021 consumer prices (26 c€/kWh)	If sold as EV charging price (40 c€/kWh)	If sold with 2022 consumer prices (65c€/kWh)
Yearly total revenues	-6153 €	-11486 €	-17776 €	-27350 €	-44442 €

Obviously, by EV charging or by selling the electricity to the community members, the current solar park could be used 7 times financially more attractive than the present situation. There is approximately a potential of 5-38 k€/year of profit, that could be achieved within the Aardehuizen community. So therefore, parties need to agree on charging methods and a sound business model and accounting needs to occur as well as contracts between parties/inhabitants. An easy way of bringing external sources with a 20k€ /year potential, would be attracting EV charging to external people and pricing [20]. Of course, this potential assumes that the consumption occurs with a smart charging mechanism, and no solar power goes back to the grid (these numbers are figurative). All these numbers and future scenarios will be further developed in the next chapters, including the technical, capacity and contractual challenges.

2.5 Phasing out of net metering: a game changer

Considering these conditions, fixed term and variable contracts are at this moment more advantageous than dynamic pricing in the Netherlands. With net metering, you can simply buy most of your energy at the same price you sell it. Therefore, there is no need for the energy suppliers to buy each solar kWh produced for 9c€/kWh without any incentive. Instead, it can be sold for an average of 65c€/kWh, meaning that the avoided costs amount to 1200€ per year thanks to net metering. With a payback time of around 2.5 years for solar panels, these panels generate an economic yield and environmental profit. This is a favourable situation for people who can invest, but people who cannot invest, are not able to benefit, which is an unjust situation. More discussions are made in D3.4 on this topic.

From 2025, the net metering is gradually waived. The earnings per year (based on 22 c€/kWh –costs in 2018) and how it works out financially, is illustrated in Table 5 [14]. However, there are many uncertainties on electricity price per kWh now and in future.

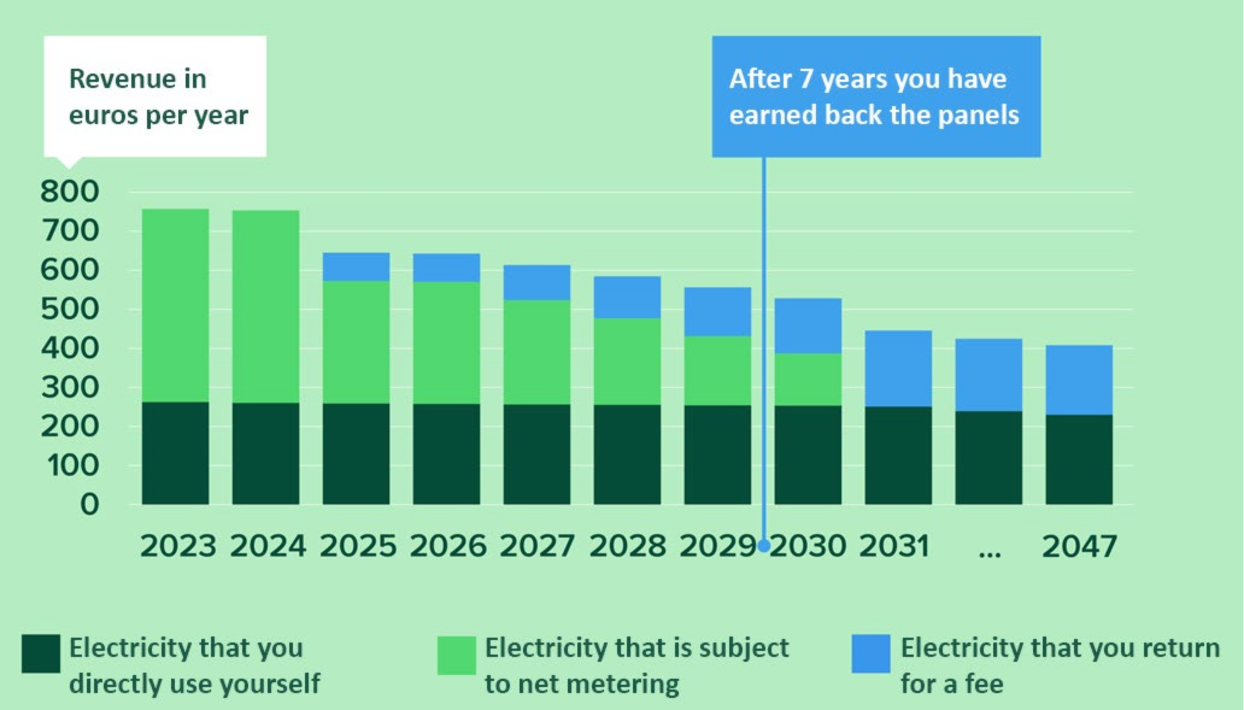


Figure 5. Illustration of the Dutch net metering and its gradual phase out until 2031 [14]. The dark green represents self-consumption (own supply), light green exported as net metering (where import costs = export revenues) and blue sold to the grid with a lower fixed prize

Approximately 35% self-consumption is assumed, which is in line with findings in other literature. The earnings will of course diminish by the change of this price difference, where here it is illustrated between 22 c€/ kWh to 9 c€/kWh, although at this moment the first bar should be based on 65c€/kWh. So, the earnings/avoided costs in the beginning will be larger (light green and dark green).

While those earnings will decrease over time due to the withdrawal of the incentives, the smart energy management platforms and managing timely consumption, will become more attractive on savings, especially in the form of dynamic pricing. The next section will abord dynamic pricing according to our results and compare different billing scenarios.

3 Smart Neighbourhoods in Olst: Business case of current infrastructure with dynamic contracts and feasibility mapping of future flexibility

Net metering will be reduced from 2025 onwards and phase out in 2031, meaning there will be an increasing price difference in import and export costs. Therefore, before the full phase out, it is expected that dynamic pricing will be more beneficial as the incentives will not cancel out the timely variations of costs. In this section, the parameters that influence this according to different ambitions of Aardehuizen, will be depicted.

The dynamic pricing will lead to more variations of the price over time, yet also more opportunities to incentivise actions that help the green energy transition and sustainable behaviour. To start with, by modelling, the smartness and automatic flexibility is compared to no control or technological improvements. The current situation of Aardehuizen has been modelled with different optimisations without considering any of the grid fee or tax aspects (D5.1) and is detailed in section 6.2 being focused on wholesale day-ahead electricity market with 2021 data and 15 min resolution with different optimisation purposes. The focus here will be on the outcome of the results. Please refer to section 6.2 for further technical information about how these models calculate different aspects.

At the Aardehuizen neighbourhood, there are 23 households. Even for a relatively small community the smart control doesn’t only reduce considerably their emissions but an increase of the grid stability by reducing their overall peak curves has been observed from simulation studies.

The prices are dependent on the type of contracts and closures of the contract that has been agreed upon by the prosumer as indicated. Yet the simulations are made in such a way to include the whole community and assumes that the individual 23 houses are acting as one entity and they share their solar power before importing/exporting. That does not have any effect on peak and emission minimization, and with net metering if equipped with enough PV, the difference in individual bills is slight. However, there is a major difference between houses that do not have any PV or limited PV (as demonstrated in previous sections).

For the dynamic pricing, as not containing net metering, this might affect the individual outcome and the whole community benefits becomes much more important economically. Be aware that due to net metering, the total price does reflect negligible improvements for fixed and variable contracts, and here expressed only in case of dynamic pricing. Fixed and variable contracts, has no change in regard to cost minimization and therefore no business case for smart control.

Table 8 summarises the result that is presented for the dwellings of Aardehuizen in section 6.2, for the current situation with dynamic pricing. “No control”, meaning no smartness is taken as reference and compared to different smart optimisations: peak shaving (contributes to grid resilience), cost minimization and CO_2footprint minimization.

Table 8. Aardehuizen results depending on difference in optimisation

Type of Optimisation	Total price	Emissions	Peakshaving	Max import kW	Max export kW
Peak min.	-104%	-8.7%	-20%	-80%	-18%
Cost min.	-147%	-13.8%	-6%	+4%	-3%
Emission min.	-109%	-20.9%	-2%	+6%	-2%

Overall, there is about 20% of improvement space although the focus is resilience of the grid and reducing maximum import by peak minimization and still having a reduction on emissions or reducing the emissions then the resilience of the grid is reduced slightly or almost same. The next subsection details the outcomes for 2021 and 2022.

3.1.1 Neighbourhood with dynamic pricing including solar carpark

Table 9 gives the results of the current infrastructure results of Aardehuizen, under no optimisation and different optimisations based on energy price of wholesale market. Additional to our last deliverable D5.1, does not include only the cost of energy, but also includes energy supplier, grid, tax and margin costs, plus day ahead market prices. To further balance both individual and societal benefits, the grid import/export limitations are applied, and results are given as well in the right side of the Table 9.

Table 9.Current situation energy bills of Aardhuizen, inclusive all fees (supplier, grid connection, transport…) and taxes

Current situation as community*, Yearly electricity bill per household	**No constraints (capacity limits)**					**With import / export limitations**		
	No Control	**Peak shaving**	**Cost Min**	**CO2 min**		**No Control**	**Cost Min**	**CO2 min**
Dynamic 2021	40	-195	-191	-159		40	-191	-187
Dynamic prices of ratio with 5 as an average estimation of 2022*	381	63	-46	69		381	73	87

*In case the whole community is acting as one juridical identity that pay all from one meter and make the divisions of individual cost internally (results are given for an average household.)

**current full year 2022 data is not available for obvious reasons; therefore energy prices are multiplied by average price ratio between 2021 and 2022, at this moment, fivefold for the supply of the energy cost / gains (this fivefold is observed in Table 3 where price components are explained)

In case of dynamic pricing, even in best case scenario with all the cost optimisation, the average electricity bill seems to increase. That comes from the fact of net metering. Once it will be phased out, the average household will pay 1700€ (section 3.4.1) instead of -190€ yearly if they stayed with fixed/variable contract. Even no control dynamic pricing seems better option, yet smartness yields 235 – 440 € a year as a price difference to the household, according to respectively 2021 and 2022 pricing.

As our modelling is based on wholesale prices, an optimisation algorithm such as cost minimization does not include the additional fees. The optimal business case for individuals is still peak shaving, and this increases grid stability. With the increased prices of 2022, dynamic pricing and cost optimisation result in a cheaper bill for the households. The earnings will be larger for bigger communities and industrial areas.

Some of the simulations could be redone with all additional taxes and pricing schemes instead of it being only based on wholesale market prices. Yet it is not expected to have a substantial impact on the outcome per household, as import/export limitations are also a way of reducing the exchange as an additional fee per kWh would do.

3.1.2 Solar carpark with e-mobility

Subsection 3.4.2 sketched the current situation and the possibilities only from the c€/kWh perspective. This assumes there will be a constant demand corresponding to production to give only a potential. Yet, this is a very rough estimate of the maximum potential. As you may see from the estimations made in the previous subsection (4.1.1) and the difference between no optimize consumption; various prioritizations have impactful results in the electricity bill.

Here we assume 3 EVs charging from the solar carport with a total of 40000km a year (~6000kWh with 0.150 kWh/kM (Nissan Leaf 42 kWh)) in our modelling. The current average of Euro 95 at 2.21€ /L, and 4.7 L/100 km for an ICE car is assumed to compare what is currently happening [21] and what could be the benefits of EVs [22]. The EV's here are not smartly charged, there is no community battery involved, which will be presented in the next subchapter.

Table 10. Representation of different costs depending on the type of car charged

	Cost of mobility per km	**Cost of mobility**	**Revenue of PV exported (9c€/kWh)**	**Electricity bill**	**Total energy bill**
3 ICE + Solar carpark	10.38 c€ / km	4164	-6153	-6153	-1989
3 EV + solar carpark	1 c€ / km *	541	-6153	-5611	-5611

*Since the surplus energy is exported as 0.09c€/kWh, and all charging occurs from solar energy supplied by the solar carpark itself.

As energy plus, the terms 2021 and 2022 are not varying due to net metering therefore the table represents both years. As is evident, if solar charged, the mobility costs are decreased to 1/10th. The ratio of the costs is not the same as EV efficiencies and ICE efficiencies, and the source of energies are different. It is evident from this table that if all were solar charged, 1.2 k€ could have been avoided per vehicle per year for an average Dutch driver. The savings would increase if the distance travelled per year increases.

It will also be interesting to see the EV charging sharing effects if there are more than 3 EV's at the parking location. Another aspect would be EV car sharing, as the maintenance costs of EVs are expected to be less and with more km, the avoided costs are increased.

Assuming a lifetime of a car and EV at 200.000 km; the total lifetime savings of an EV that is solar charged are around 18k€. If assumed that EVs double in km ICEs (400.000 km as no gearbox, combustion and additional mechanical systems vs electrical drive-in wheel), yet an EV needs a battery change every 200.000 km costing around 10k€, in this case the estimated lifetime savings are around 26 k€.

Yet if they are not solar charged, this difference becomes negligible, especially with the current prices for the import of electricity (65 c€/kWh inflection point). These calculations assume all solar charged or net metering. The next section will investigate dynamic pricing. Smartness, community battery and complete system implementation is modelled for a flexible, future proof and smart neighbourhood.

3.2 Business case: Future scenario of Aardehuizen with smart grids, with e-mobility, community battery included

In Table 11, a future scenario is modelled and the electricity bill is calculated for: 80kWh community battery, 3 EVs with 42kWh battery, a total PV installation (rooftop and solar park inclusive 130kWp) with smart control and different prioritization to check what the future looks like if we implement the measures that we were talking about. The advantages are summarized in the introduction of chapter 4, and we are here considering only costs under dynamic pricing as community.

Table 11. Future situation as community*. Yearly electricity bill per household

	No constraints (capacity limits)				With import / export limitations		
	No Control	Peak shaving	Cost Min	CO2 min	No Control	Cost Min	CO2 min
Dynamic 2021	-117	-237	-56	84	-117	-232	-223
Dynamic prices of ratio with 5 as an average estimation of 2022**	389	17	-84	385	389	25	57

*In case the whole community is acting as one juridical identity that pay all from one meter and make the divisions of individual cost internally (results are given for an average household.)

**current full year 2022 data is not available for obvious reasons; therefore energy prices are multiplied by average price ratio between 2021 and 2022, at this moment, fivefold for the supply of the energy cost / gains (this fivefold is observed in Table 3 where price components are explained)

For 2021 prices in dynamic tariffs: cost minimization of no capacity constraints, in a future scenario, result in less optimal electricity bill, as it only considered the electricity price on the wholesale market. It turns out, that if supplier fees and grid fees are included; peak shaving is the best solution for the grid as well as for the energy bill of the community, which is a win-win for all parties.

For 2022, as the price increase of the wholesale market is so significant, the conclusions of D5.1 remains true, meaning one could optimize in his/her financial benefit smartness and reduce the resilience of the grid, as in case of "no capacity limit". Import/export limitations are always correcting those type of scenarios, where the best financial case remains "peak shaving", meaning locally consuming what is produced and having the smartness there to help the grid.

To ensure the social benefits and resilience of the grid (and DSO, BRR interest): the case of cost optimisation with no constraints should be further investigated to avoid bigger communities or industries to cause resilience issues in the grid.

Coming back to the implications of the prices for the community or individuals, implementing measures as battery or EVs will significant benefit Aardehuizen's electricity bill. EVs and batteries, considerably decrease the dynamic pricing costs although their overall consumption increases. The prices include all grid fees, taxes and supplier margins. That is also inclusive of additional EV charging etc. Yet avoided costs of not anymore travelling with 3 ICEs (4 k€ - section 4.1.2) is not inclusive in table 11, neither the phase out situation in the near future (1.9 k€ avoided per household 2030 onwards in section 4.1.1). So avoided costs are actually 5.9k€ that does not yet appear in the current balance sheet. On the other hand, it does not include the initial installation of solar installations or battery capex, LCOE and LCOS as it is case and supply availabilities dependent. The next chapter will do a sensitivity analysis on those costs.

3.3 CAPEX and Sensitivity analysis

In this chapter, we investigate the situation when all the investment are made by the community and how the investments can be financed.

The initial investment of a new small size EV (such as Sono Sion, Nissan leaf, 4 door 5 person) is at this moment around 30k€. The total life savings are very close to the initial investment per car, but that needs to be seen as long term investment.

1.2-1.4€ /Wp solar installation is what a residential rooftop installation cost, so 130kWp would require an initial investment of 156-182 k€ , and for the average of community, payable in 3 years. LCOE is detailed in 4.3.2.

Battery costs are discussed in 4.3.3. with their capex.

3.3.1 Levelized cost of electricity (LCOE) and sensitivity analysis

Levelized cost of electricity (LCOE) is introduced in D5.1 with formulas, but in simple terms, it means: how much money has been paid to get 1 kWh returned from the system. LCOE for PV, is dependent on the type of installation and its location (due to solar irradiation variances on Earth). Average Dutch solar irradiation is around 1050 W/m^2, which is in between 950-1120 W/m^2 Global horizontal Irradiance (GHI) results done for Germany by Fraunhofer. In case of shading or inefficient systems or aging, it will be closer to 950 W/m^2. In case of efficient functioning, 1120 W/m^2 seems a good estimate as in the Netherlands there is much diffuse radiation and in recent years, this yield has increased. For Aardehuizen, because of large rooftops (>30kWp) for a 1120 W/m^2 GHI, which is between 5-9 c€/kWh depending on factors that will be also cross checked in the following sensitivity analysis. The 9c€/kWh proposed by energy suppliers is not so profitable for small rooftop installers if there is no net metering. And for communities, although there is a slight positive difference, they need to ensure their self-consumption; as they are making profits mainly on the self-consumed part (often 35% of the production without storage involved).

Figure 6. LCOE of PV systems in Germany based on system type and solar irradiation (GHI in kWh/(m²a)) in 2021, [17]

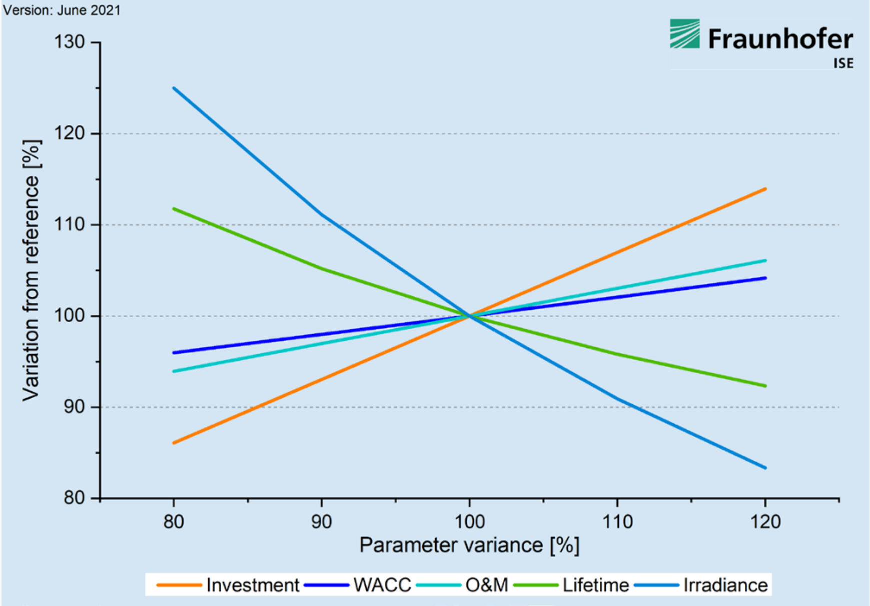


Figure 7. Sensitivity analysis of a small PV system with a GHI of 1120 kWh/(m²a) and investment of 1300 EUR/kW [17]

The sensitivity analysis in Table 7 shows how much influence a parameter has on the financial outcome of the LCOE of PV results shown in the previous Table 6. Lifetime and operation maintenance (O&M) are not so influential, and main actors are irradiance and investment (€ / kW). Irradiance does vary 5% year-to-year, of course, so it might have an increased influence as parameter if climate change varies the solar irradiance significantly. Therefore, for the Dutch case, initial investment will be the main variable that will affect LCOE. Yet, weighted average cost of capital (WACC) here was based on 1.2 % of inflation, as the study was made before the geopolitical events. Onshore Wind seems to be comparable with large to utility scale solar farms, yet offshore investments seem to be worse than rooftop LCOEs according to Table 8.

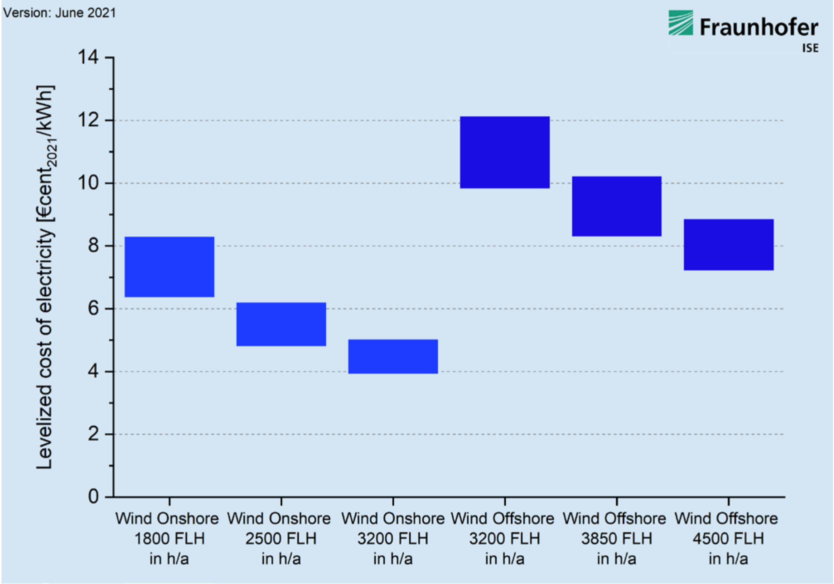


Figure 8. Representation of the LCOE of both on and offshore wind power [23]

For Aardehuizen, it could have been an opportunity to further invest in Wind Onshore, but such turbines are costly, and the neighbourhood is already energy plus. The synergy of PV and wind could have resulted in better self-consumption curve, but modular and ease of installation of solar panels, as well as absence of noise, solar installations are being dominant in the village. To increase the self-consumption and enable the smartness to its full potential, one of the measures was also to install a battery. The battery case we simulated is close to 50%, this is depicted in the middle section of the Table 9.

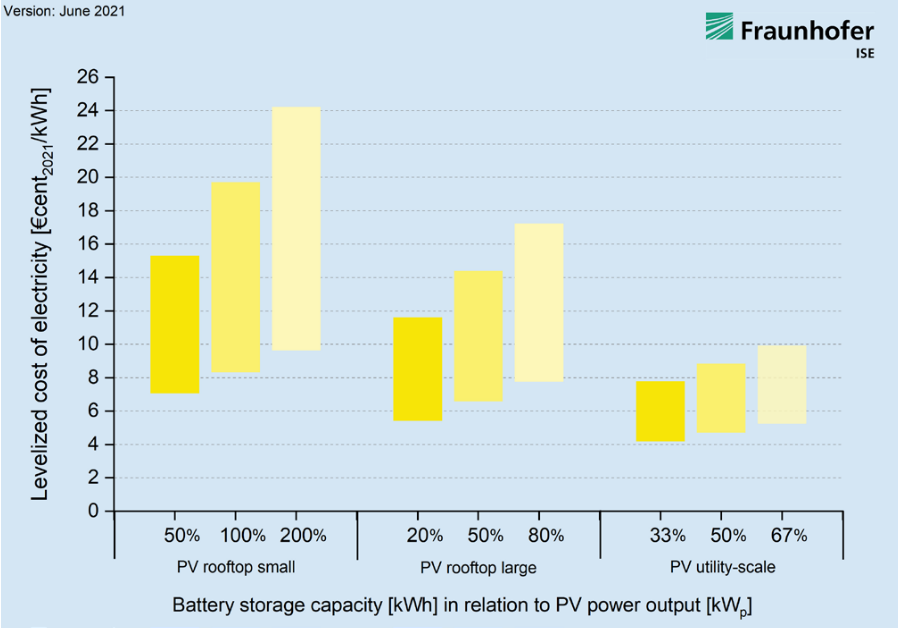


Figure 9. LCOE including battery [23]

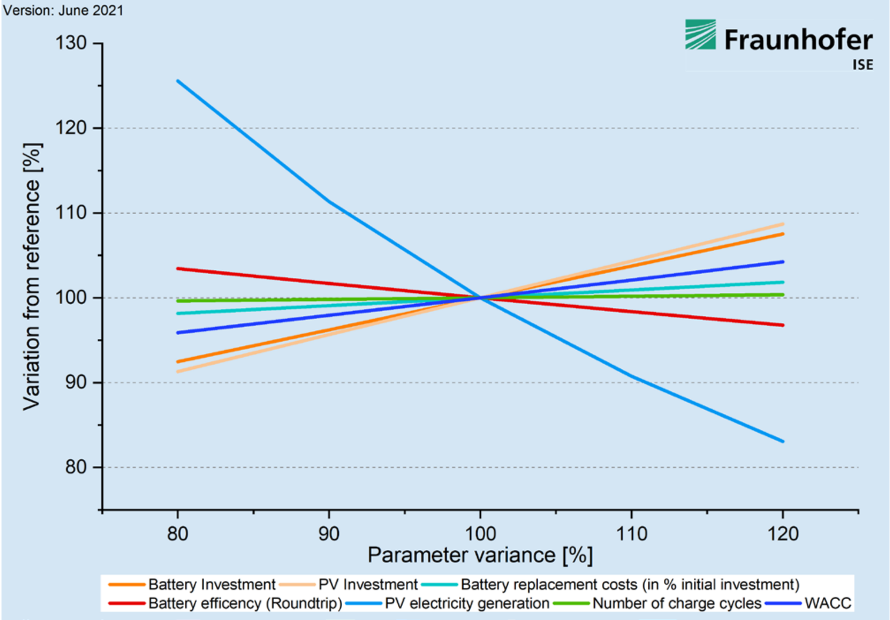


Figure 10. Sensitivity of the initial investment [23]

There are many influencing parameters: battery and PV initial investments are second and third sensitive parameters that should be considered. These numbers also include the OpEx and the battery replacement. PV electricity generation and PV performance suddenly becomes the most important parameter; therefore it is wise not to oversize the battery for any application including the community of Aardehuizen.

This comparison is made regardless of the difference of technology of storage. Next subsection will detail levelized cost of storage.

3.3.2 Levelized Cost of Storage (LCOS)

Comparing storage devices from a financial perspective is challenging. Looking at only the cost per kWh of capacity does not account for other characteristics important in differentiating storage devices, such as round-trip efficiency and the number of cycles in a storage's lifetime. This leads to a skewed overview when comparing technologies. To make a more useful comparison, Levelized Cost of Storage LCoS) is useful. The LCoS is similar to the Levelized Cost of Electricity (LCOE) but is more suited when comparing storage devices.

There are different methods available for calculating the LCoS, depending on the information available and the precision required [24]. Here, the choice is made to use the formula given below, where cycles are defined as a full charge and discharge event of a storage device.

$$LCoS\left(\frac{\$}{kWh}\right)=\frac{Investment\ Cost\ per\ kWh\ \left(\frac{\$}{kWh}\right)}{System\ Lifetime\ (cycles)*Roundtrip\ Efficiency\ (\%)}$$

Note, for the investment cost only, the CAPEX was used. Additionally, although the Depth of Discharge (DoD) also differs per storage device, this was not considered when calculating the LCoS as for many technologies it changes over time and using a single value would not be precise. Finally, both power and ramp rate, which in addition to capacity are two important criteria when evaluating the flexibility [25] of a storage device, are not considered.

The table below shows the calculated LCoS per technology for a 2018 scenario and a 2025 scenario, both per kWh and per 80kWh (the required storage capacity at the Aardehuizen, see D5.1). The input values per scenario are taken from [26].

Not every technology examined is suitable to use at the Aardehuizen. Pumped hydro power and compressed air energy storage are not possible or at the very least highly impractical. In addition, flywheel and ultracapacitor storage devices are more suited to high power and low-capacity situations, where many cycles are needed. Due to the storage being used on an intraday basis at the Aardehuizen, a high volume of cycles is not required. Therefore, the choice of technology falls clearly on either lithium-ion or redux flow. As lithium-ion is a more developed and proven technology, the choice of lithium-ion is logical and intuitive. The annex A also gives an overview of quotations that research team gathered based on off shelves solutions and installers offer.

Table 12. Overview of the LCoS and characteristics per storage technology, for 2018 and 2025

	Current Scenario (2018)				**Projected Scenario (2025)**				**LCoS per kWh (2018)**	**LCoS per kWh (2025)**		**LCoS per 80kWh (2018)**	**LCoS per 80kWh (2025)**
Technology	**Lifecycles**	**Roundtrip Efficiency**	**Cost per kWh**		**Lifecycles**	**Roundtrip Efficiency**	**Cost per kWh**						
Lithium-Ion	3500	86	469		3500	86	362		0.16	0.12		12.47	9.62
Lead Acid	900	72	549		900	72	464		0.85	0.72		67.75	57.28
Redux Flow	10000	67.5	858		10000	70	650		0.13	0.09		10.17	7.43
Sodium Sulfur	4000	75	907		4000	75	669		0.30	0.22		24.19	17.84
Sodium Metal Halide	3500	83	928		3500	83	669		0.32	0.23		25.56	18.42
Zinc-Hybrid Cathode	3500	72	551		3500	72	433		0.22	0.17		17.49	13.75
Pumped Hydropower Storage	15000	80	165		15000	80	165		0.01	0.01		1.10	1.10
Flywheel	200000	86	11520		200000	86	11520		0.07	0.07		5.36	5.36

Compressed Air Energy Storage	10000	52	105		10000	52	105		0.02	0.02		1.62	1.62
Ultracapacitor	1000000	92	74480		1000000	92	66640		0.08	0.07		6.48	5.76

3.4 Potential ecological savings and energy/emission payback time

Greenhouse gas emissions of PV panels are included on our CO_2 saving calculations and it is between 40-60 gr CO_2 eq / kWh. Energy payback time of a multi-crystalline silicon PV module is 2.1 years in northern EU[27]. The panels are designed to last 25 years, meaning that nearly all the energy consumed to make the modules would be at least 10 times returned back during its lifetime. Therefore, investing in such renewable technologies would always result in less energy dependence and emissions.

The emissions to produce the PV panels and batteries, in the future, will be less as they will also be produced with green energy or greener national electricity mix.

Xu et al in a recent study quotes that: “ greenhouse gas (GHG) emissions per kWh of lithium-ion battery cell production could be reduced from 41 to 89 kg CO_2 in 2020 to 10 to 45 kg CO_2 in 2050, mainly due to the effect of a low-carbon electricity transition.”[28].

The same applies with e-mobility and EV production. In a near future, industries will have smart production lines that are coupled with renewable generation that will help them to reduce their energy cost and stay competitive.

4 Technical Designs

This section will explain the technical designs that are developed for the Dutch demonstrators. These solutions are specifically made for the local energy communities, considering their input, wishes and data, yet common applicability and scalability is considered. Firstly, individual residential houses monitoring and control systems are summarized in D5.1 and improvements are indicated here. Secondly, community shared locations, such as common house and solar charging station systems will be detailed from technical perspective. All these works are done to prepare to implement in real life, the business cases or revenue streams that have been depicted previously in chapter 4.

4.1 Residential Houses Monitoring and Control systems

15 monitoring systems will be rolled out to the households in Aardehuizen community. One different monitoring system is deployed in Vriendenerf. The number of volunteers grows every month and further installations of monitoring systems are being planned. Our aim is to cover the whole neighbourhood. Below the systems which are being used for monitoring and control purposes are briefly described.

4.1.1 Loqio Advanced Monitoring systems

Technical details of the Loqio systems as well as software management platform was explained in D5.1. Now, eight additional monitoring systems are implemented in the households, and a photo of the systems before Loqio has deployed them is shown in Table 11.

Figure 11. Monitoring systems

4.1.2 Saxion E-boiler control system

The goal is to view the shifting effects on the energy profile of a household if an E-boiler is used as buffer energy storage. For this purpose, there are two requirements that need to be implemented: the state of charge model which views the energy capacity of E-boiler and determines if it must be enabled or disabled and actual hardware that does so. Another requirement is that control hardware must be non-invasive in order not to void the warranty of E-boiler, this is where Saxion E-boiler control system comes in.

Table 12 below shows the concept plan for the system design with the power flow to components of the E-boiler control system.

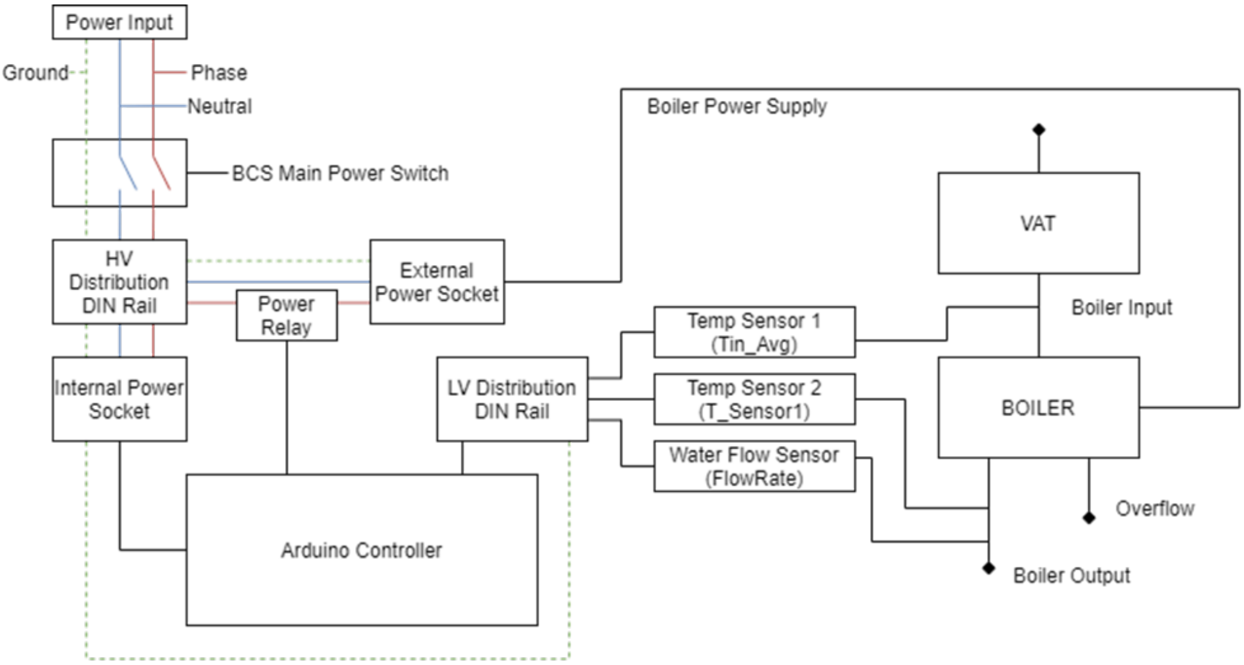


Figure 12. Concept system design of the E-boiler control system

Table 13 below shows the black box diagram of the Saxion E-boiler control system inputs and outputs.

Figure 13.Black box diagram of Saxion E-boiler control system

The DEMKit software receives the measurement signals (temp. and flow) from the E-boiler control system and keeps track of the power status of the E-boiler. The state of charge model then uses these measurements calculating the state of charge of the E-boiler and whenever it needs to be charged (be turned on) or it is charged and must be turned off.

These measurements can be viewed on the developer dashboard (Grafana). Figure 14 below shows recorded data by the E-boiler control system.

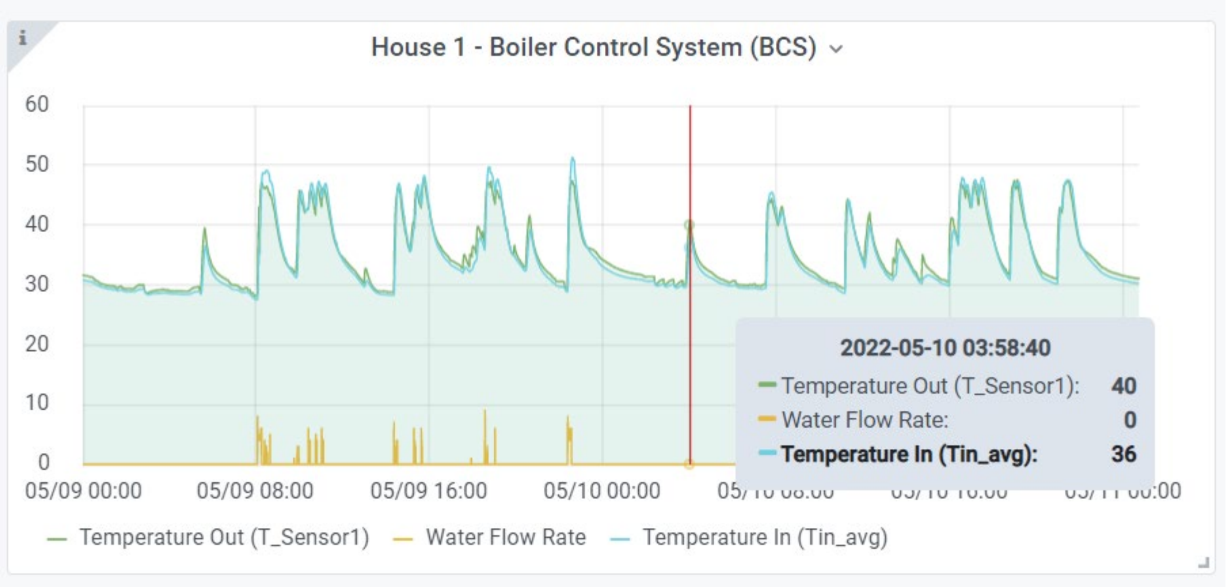


Figure 14. Data recorded by the E-boiler control system.

The E-boiler system can be controlled and shifted by DEMKit. However, the state of charge model is currently in the re-work and a re-design of the control system is also ongoing.

The results of the shifting E-boiler can be viewed on the energy profile of a household which is monitored by a monitoring system designed by Saxion.

4.1.3 Saxion Monitoring system

The monitoring system designed by Saxion University of Applied Sciences monitors a smart meter at a household through P1 port. Figure 15 and Figure 16, below shows the monitoring system with its housing.

Figure 15. Monitoring system

Figure 16. Housing of the system

The monitoring system’s main processing unit (ESP32) reads and sends the data to a broker API where a modelling and control tool DEMKit has access to it for the simulations and contorl, i.e. E-boiler control system.

Figure 17, shows the data recorded by a monitoring system at the house where E-boiler is also installed. A peak consumption can be see at 4.00AM. In the Figure 14, above, it can be seen that the temperature sensors start to record the rise in temperate and flow meter meaning the boiler is active.

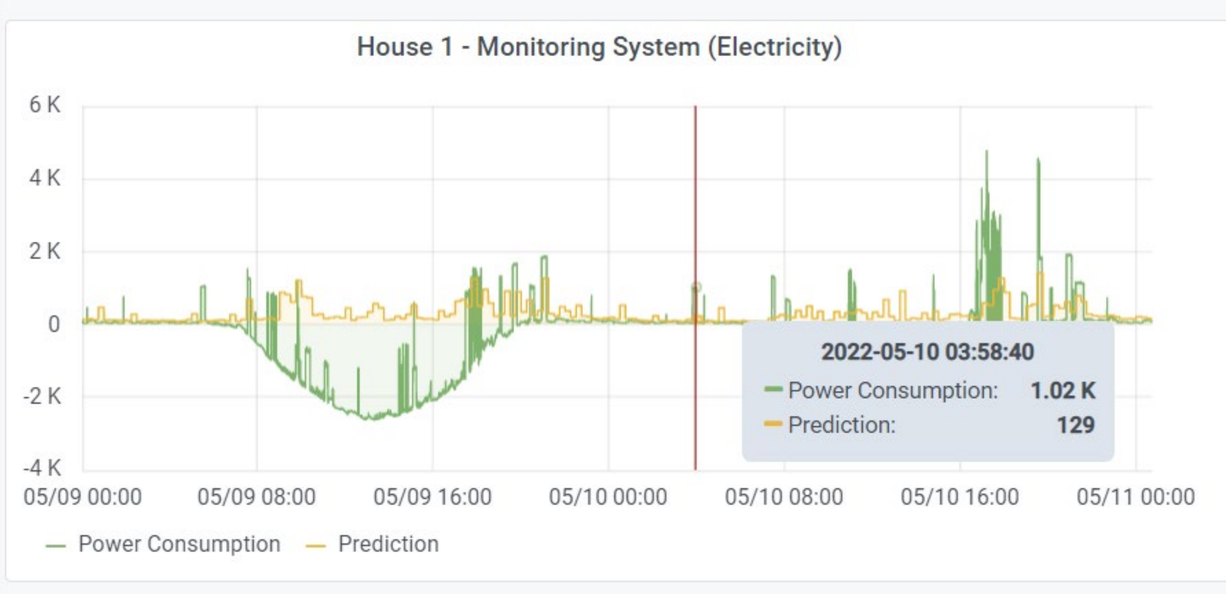


Figure 17. Data recorded by monitoring system.

4.1.4 Heating system in households

A typical heating system of Aardehuizen is shown in Figure 18.

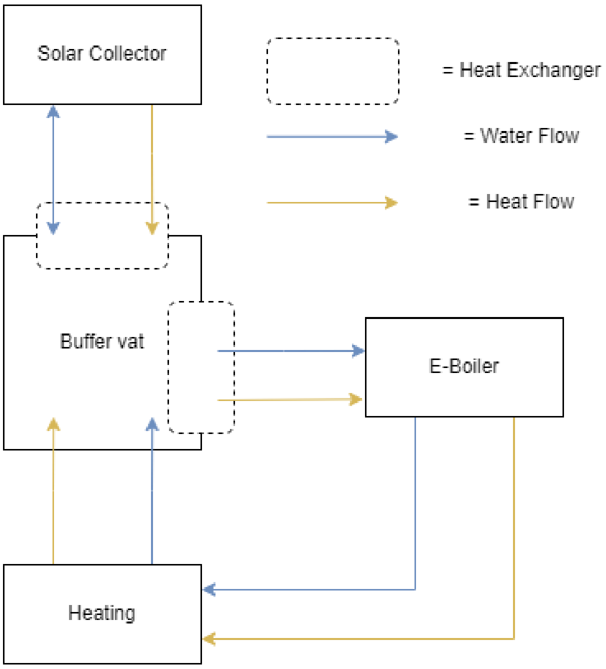


Figure 18. Representation of the boiler including solar thermal

4.1.5 Verification of the data acquired and control

Real data is intact and corresponds to the monthly bills that are received by the inhabitants, with an error of less than 1%. This is negligible and could be even due to metering differences or averaging method differences.

Besides, the control circuits are verified and can turn on/off the boilers as expected. A boiler control user manual has been worked on and will be made available when the improvements are finalized. State of charge estimation is complex to reach high accuracy so further development will be made during the SERENE project on those solutions.

4.2 Solar carpark and solar charging of EV

Aardehuizen community's solar park annually generates enough to charge 26 EVs theoretically [19] considering an average commitment of 15.000 km per year. So, there is great potential for this solar carpark to transition towards solar e-mobility (Figure 19). This potential is already noticed by one of the inhabitants. One EV charger was already installed; however, it will remain for its owner's private use and will not be shared.

Figure 19. Solar carpark of Aardehuizen

Unfortunately, the other Aardehuizen residents do not yet own EVs, though that does not mean that they are heavily involved with fossil based transportation, as cycling consist of 27% of all commitments in the Netherlands [29]. With the trends in fossil fuel prices, and their willingness for a clean mobility, they are seriously considering the ownership of EV, which also will be subject of our next deliverables. Yet the roadmap and technical designs are already analysed, and findings are discussed with the neighbourhood.

Considering solar inverter’s nominal/maximal output (60kW / 70 kWp), it is best to have three additional Alfen Pro-Line Single 22kW EV chargers that would be smartly controlled and shared amongst the local energy residents. There will be four phases of smart controlling and smart mobility, which are summarised in Figure 20 and detailed further.

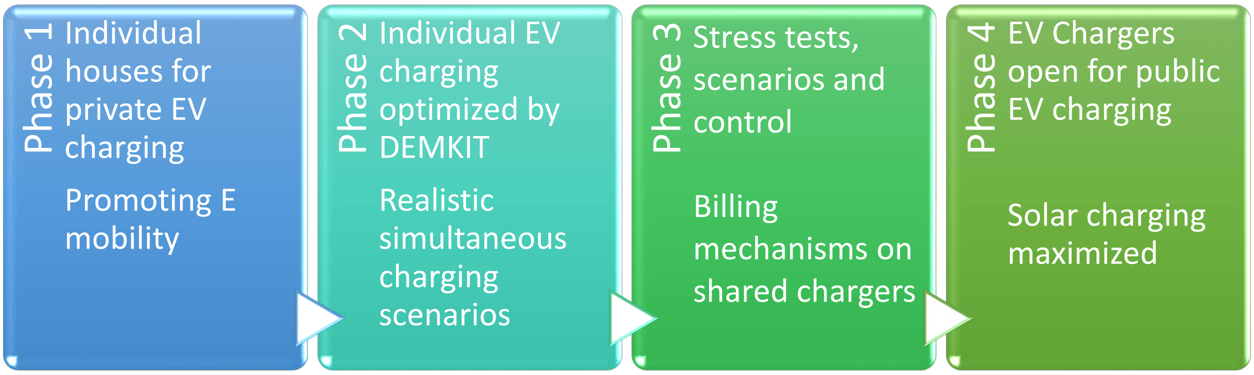


Figure 20: Distinct phases of technical designs and implementation of solar mobility

Phase one is taking place in Vriendenerf by testing the same type of chargers. The charger is shown in Figure 21. For Vriendenerf, there is no solar carpark as in Aardehuizen, but they already own EVs, so their experience is also encouraging Aardehuizen to invest in EV cars.

Figure 21. Alfen pro EV charger in Vriendenerf charging inhabitant’s EV by solar power

The same kind of chargers are installed with our encouragements and their own investments, with a bit less power, connected directly to the house rooftop and the house electricity network is used. That is why the charger’s power is limited to 11kW. The installed EV charger in Vriendenerf, its identification (RFID) and charging events occur seamless so far. That promotes and allows us to test further.

Phase two would be that we would use our own energy management systems to optimize further the solar charging and harmonize the consumption of the whole neighbourhood. That includes the solar predictions and best moments to charge from costs and environmental perspective. From the individual EV charging data and mobility patterns, scenarios can be constructed more realistically for multiple charging stations optimisation.

In phase three we will conduct some stress test for scenarios to test limits and cure if problems occur. We will try to allow that people share the charging station by a billing mechanism, especially for the solar park.

To finalize the systems, and if market conditions allow it, making the EV chargers open to use publicly and effectuate billing mechanisms to those who charge their car from the chargers of the community. Maximizing the solar charging and therefore making mobility as clean as possible is also one of the end goals.

5 Conditions of Implementation

As residential houses, both communities are the end of the supply chain of the energy grid. The scope is limited to retail market (Low Voltage), yet the residents are both producing and consuming and therefore are consisting of prosumers. Their energy bill is limited to electricity and if used biomass (wood) – no gas and gas network involved.

The status of Aardehuizen under three different optimisation criteria is the following: peak shaving (grid stability), cost (earnings of the prosumer) and CO_2 emissions have been calculated (see section 6.2). The optimisations are performed using Demkit [30] for the year 2021 at 15 minutes time resolution. From the data perspective, for the cost optimisations, solely the Dutch day-ahead market prices of 2021 are used [31]. The energy mix data of the Netherlands at a given time is used [32] to calculate how much CO_2/kWh was produced by importing from the grid at that time, where negative energy (delivering back to the grid) leads to negative emissions. The sum of all import/export lead to the emission result. The methodology, formulas and technical results are mentioned in next subchapter.

The consequences of the different types of energy supplier contracts, additional costs, levelized cost of electricity, levelized cost of battery and return of investment, rather cost wise or emission wise, is discussed in chapter 3.

The connection limits and other technical related conditions will be detailed in subchapters 6.3. We have 2 topologies of connection to the grid:

- Symmetrical: all 23 households have similar PV capacity, more or less depending on the size of the household. Their limitation to import from and export to the grid are same, and often smaller than what their capacity allows.
- Asymmetrical: Solar carpark can export way more than it can import from the grid. It has also the biggest and the most flexible loads in terms of time rescheduling, EVs.

The capacities, the limiting conditions and boundaries would be detailed after the following sub-chapter too, to depict implementation conditions.

5.1 Electrical Connection limits to the grid

Figure 22 explains the electrical connection diagram of the Aardehuizen and Vriendenerf neighbourhood. The dwellings are symmetrical and all have standard connection as they are quite like a standard prosumer (3x 25Amp further explained in Table 13. Grid fees according to three main Dutch DSOs; Connection and transport costs applicable from July 22 until Jan 23 (numbers are limiting only the import from grid) [34], [35], [36]).

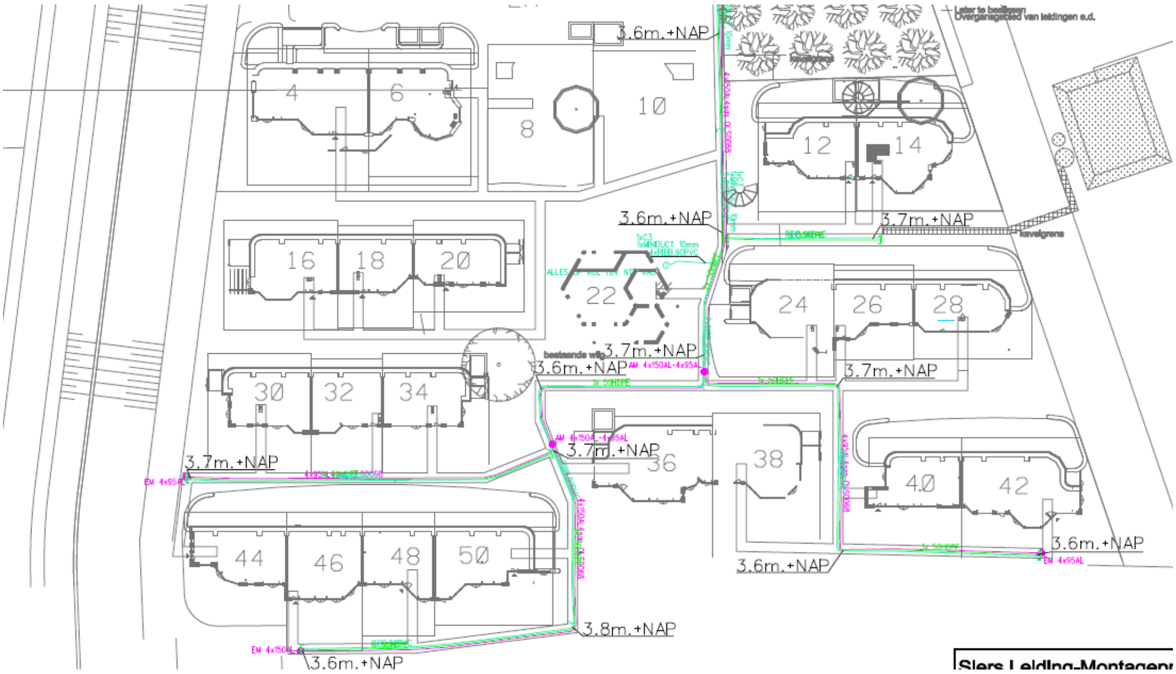


Figure 22. Electrical diagram of Aardehuizen neighbourhood

Figure 23. House electrical connection diagrams (blue and green) of Vriendenerf

The solar carport has a different status, it is one big prosumer of 70kWp installation, one non controllable EV charger and a special connection point. Legislation and economic conditions are briefly touched upon here, as well has the future ideal conditions of implementation will be discussed in the subchapter after the next one. Next chapter will detail the feasibility of current and future conditions.

5.1.1 Within Dwellings

Table 13 indicates the type of connections that DSOs provide for small consumers (households) ([33], [34] , [35], [36]). The table also gives you an idea about the cost increase if a capacity upgrade is needed, and the additional connection costs that it brings. These cost are including the biggest 3 DSOs in the Netherlands, so representative of 94 % of the Dutch market share [11].

Table 13. Grid fees according to three main Dutch DSOs; Connection and transport costs applicable from July 22 until Jan 23 (numbers are limiting only the import from grid) [34], [35], [36]

Phase x Ampere	Power limit	Application	Yearly costs for connections (€ inclusive VAT)			Upgrade costs*
			Enexis	**Alliander**	**Stedin**	
1x10 A	2.2kW	Garage / open spaces	97	97.95	64.3	-
1x 25A – 40A	5.5 -8.8kW	Old house connections, Tiny houses	207	248.34-***	207.3	258.69
3x 25A	17 kW	Standard connection	241	248.34	229	258.69
3x 35A	24 kW	Big Houses / EV fast charging	903	944.85	875.2	314.79
3x 50A	34.5 kW	Houses with Heat pump and EV fast charging	1312	1374.53	1282.2	314.79
3 x 80A	55.2 kW	Limit of private consumer (klein gebruiker), EV ultra-fast charging	2131	-	2098.5	314.79
3 x 160 A**	110 kW		5600	-	-	-

*For Alliander [36], similar costs for others are expected

** Not counted as a standard household connection (klein gebruiker)-just to provide you an indication of costs if all the grid was meant to be used the additional costs that it would result in

The increase in capacity not only increases the yearly costs, but also adds additional workload on DSOs to enable it by changing the cables. If most inhabitants upgrade their connection in a location, that might result in local transformer LV/MV to be re-dimensioned. Plus, depending on the case, the upgrade of a single household might take two years to occur. There is a financial trade-off for both citizens and DSOs, although limiting peak the maximum import/export by smart algorithms can alleviate the situation both for the household and the substation and therefore DSO. These gird fees are often paid through the energy supplier.

The regulations suggest a separate connection fee for each customer(household), electrical (and gas) meter for each connection and allows DSO and energy suppliers to charge their customers behind the meter. That means, that people must pay these costs per household per year, and are limited to, by fuses protections as well as regulation wise, to respect the upper limit of amperes of their contract. These limits are only for importing electricity from the grid.

In Aardehuizen and Vriendenerf, all households have a standard connection, 3x25A, which means that the highest current that the house will be allowed to use from the grid is 17kW. Any change or upgrade of this capacity will bring additional costs, so a smart system might also avoid some cases in the future where they might need to have devices (fast EV chargers, heavy heat pumps) that could still be managed by a smart home energy management system that will take still be able to deliver more then 17kW service thanks to PV contributions, but that will keep the devices respecting the connection limits. Heat pumps/e-boilers and EVS are the main electricity consumers in a household and are to some degree useable as shiftable load. Smart appliances such as wet appliances etc. are easy to apply flexibility but are not the most impactful according to our results in D5.1. Heating might be impactful measure, as the Aardehuizen community often has low temperature settings. Yet ensuring a minimum comfort level could be challenging if sensors / connectivity error occurs, or the user would like to overrule the optimisations, where the device will fall back to manual mode. Therefore, the condition of cooperation by the user is essential to create positive impact. Further investigation on the behavioural impact with data and implementation of the control systems is needed and will be provided with our next deliverables and demonstrator activities as D5.3 onwards. Lab tests will be effectuated further to ensure the good functioning of the design.

5.1.2 Electrical mobility

Figure 24. Solar carpark shed

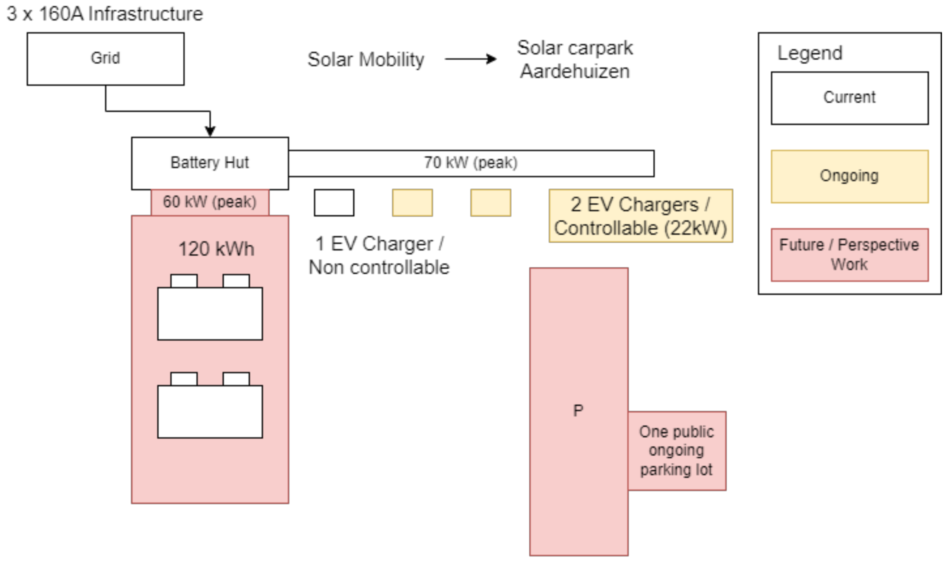


Figure 25. Solar carpark diagram for current status, ongoing implementations and perspective work

Solar carpark shed has 17kW import 70kWp export limit, due to the contractual advantages. It has the connection capacity that is oversized, but not used as extra charges would appear. So therefore, even if the additional charging stations are installed, one must make sure that everything stays at the limit of 17 kW. Otherwise, 300€ upgrade costs and 1900€ additional costs of grid fees to make the connection are levied towards the next capacity step (3x80A 55kW). A full connection will cost 5600€ and the location is out of the category "small consumer" (kleingebruiker).

The modelling is done for three individual cars that are charging, with realistic and artificial data. Yet the data is based on characteristics of another location. Taking into account the current ICE driving would still not represent the situations as EV driving patterns are different.

There are four aspects that need to be checked as condition of implementation:

- Driving patterns of EVs of inhabitants
- EV sharing preferences
- EV sharing models
- EV sharing detailed billing for fair pricing

Vehicle to grid (V2G) functionality is not available as it would need specific EVs and EV chargers, that are unfortunately out of our project budget and scope for the Dutch case. Smartness is needed, modelling the future states is needed, but the data is not yet available. Therefore, the revenues are explorative. The number of EVs is 3, because the number of chargers yet one need to consider if that would be the case and in what time frame. And if that would be shared/co-owned rather than household ownership based.

Community chargers are subsidized by the project. For maintenance and installation, there is expert knowledge in the community to intervene in small cases. For serious faults, one should also think of a common billing mechanism to pay for the repairs.

These questions will be further investigated in Business models, governance structures and acceptance of technologies within WP3. Some social cost benefit analysis is already proposed here in chapter 7, yet the input from users and user aspects are part of WP3.

5.2 *Effects of active energy community participation in the energy system*[2]

On the Effects of Active Energy Community Participation in the Energy System

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***Abstract*—This paper explores the effects of active energy communities, as defined by EU Directive 2019/944, on the energy system using simulations modelled based on a real-world ecological community. The energy flexibility of this community is optimized towards the objectives peak reduction, cost minimization, and CO_2 emission minimization. The resulting effects for different stakeholders, such as network operators and the community itself, are investigated using different performance indicators. The results show that energy imports can be reduced by 44% when peak reduction is applied. Conflicting objectives may lead to peak synchronization however, with the risk of deteriorating business cases if the network operator needs to intervene. This results in a risk where energy communities abstain from participation in energy market and its benefits.**

***Index Terms*—Smart grid, Energy management, CO_2 emissions, Optimization**

I. INTRODUCTION

The rising global warming concerns due to CO_2 emissions have resulted in policies to combat climate change. Furthermore, as European countries heavily rely on supply of energy (i.e., natural gas, oil, coal) from politically unstable countries, many countries have implemented financial instruments (e.g., subsidies) to increase the share of energy production from renewable energy sources (RES) such as PV, thereby tackling both aforementioned issues. However, higher proportions of intermittent renewable energy and the integration of carbon-neutral results in a larger demand/supply mismatch. Hence smart ways of using electricity in different sectors are required to maintain balance, system stability, and reliability of supply.

In this context, the European Union (EU) has introduced the concept of *active consumers* in its Directive 2019/944 [1] to remove barriers for consumers to participate in grid services. Through this legislation consumers can benefit from the energy transition and energy markets through e.g., selling of electricity or providing flexibility. Next to individual consumers, also the concept of *energy communities* is introduced, a concept where citizens can collectively participate and benefit from the energy transition. Such energy communities are centered within one geographical area, such as a village, where citizens often already started a local energy cooperation.

The focus of this paper is to investigate the possibilities, benefits and effects of such active energy communities in the energy system. For this, we take the exemplary *Aardehuizen* (earthship) community in Olst, the Netherlands [2]. This community have built their own sustainable earthship houses [3] and aims to decarbonize their energy footprint too. Within EU's Horizon 2020 project SERENE we investigate and demonstrate how this community can share sustainable energy internally, support the larger energy system, and become (nearly) autarkic. Using this use-case, we explore the effects of optimizing energy use e.g., by scheduling electric vehicle (EV) charging or production of domestic hot water, towards the objectives peak reduction, cost minimization, and CO_2 emission minimization. The main contributions of this paper are:

- insights in the effects of active communities; and
- how different views may affect expected results.

The remainder of this paper is as follows: Section II presents background and views of stakeholders. The use-case and model is detailed in Section III. Subsequently, Section IV presents optimization goals, simulation results, and discusses the main findings. Finally, Section V concludes the paper.

II. BACKGROUND

This section provides background information on the Aardehuizen community and energy management.

A. *Aardehuizen community*

Aardehuizen is a neighbourhood consisting of 23 ecological earthship houses [3] built in 2017 [2]. Their official vision is *an ecological neighbourhood of self-sufficient earth houses in which all aspects of sustainability are in mutual relationship in balance*. Their ambitions are to investigate how their energy consumption can be further reduced, how the remaining energy can be sourced from

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[2] This subchapter is based on our Gerwin Hoogsteen, Aditya Pappu, Bahman Ahmadi, Johann L. Hurink, Edmund W. Schaefer;, Cihan Gercek, and Richard P. van Leeuwen, IEEE ISGT EU 2022

local and sustainable (micro-)generators, to eventually become fully sustainable. Thereby, the community embraces the Trias Energetica approach [4] and aims to inspire others to follow their sustainable examples.

Currently, the energy consumption of the community is monitored through smart meters to get insight in their power profiles and how technologies such as Battery Energy Storage Systems (BESSs) can be used to increase the share of sustainable energy. Furthermore, the community investigates options for an EV sharing initiative among its members and local citizens. For this, a carport with rooftop PV is constructed with a capacity of 71 kWp. However, measures to move towards 100% sustainability are not unconstrained, and need to consider their economic feasibility, carbon footprint, and effect on society.

B. Energy management and objectives

The focus of EU Directive 2019/944 is to efficiently integrate such energy communities and their devices in the electricity system. One of the most techno-economically feasible solutions for active consumers to provide grid flexibility is the implementation of Smart Grids with the inclusion of both end-users and their devices [5]. Smart Grids is a research subject with more than a hundred thousand research papers [6]. So far, 23 Dutch Smart Grid demonstrators have investigated active engagement from the residents [7].

The Universal Smart Energy Framework (USEF) [8] provides a comprehensive overview of the stakeholders and their roles and responsibilities within a Smart Grid. Furthermore, it defines the flow of interaction and value creation among those stakeholders. Within this paper, we investigate the potential of active energy community engagement based on three different optimization goals. These objectives reflect those that energy communities, Distribution Service Operators (DSOs), and energy suppliers/aggregators may have.

1) Energy cost minimization: With the ongoing adoption of RES and inherent intermittency, it is expected that the volatility of energy markets will continue to increase [9] while incentive schemes for RES are phased out [10]. As a result, citizens can directly and indirectly benefit from fluctuating energy prices through optimal usage of their flexibility in two ways. Firstly, scheduling the operation of devices, aided by an Energy Management System (EMS), at moments of low prices can significantly lower the energy bill [11]. Secondly, handing over control of devices to an aggregator may increase the benefits further as these parties optimize a larger portfolio of customers to create value in different markets.

2) CO_2 emission minimization: Similar to economic optimization, the usage of flexibility may also be optimized to achieve ecological savings in the form of e.g., reduced CO_2 emissions. This especially concerns the import required from the main grid and consequent CO_2 emissions stemming from operating power plants. The relevant information is available [12] and might also be predictable once it is known which generators are dispatched as result of the Day-Ahead market clearing. Therefore, a similar steering signal as is used with energy cost optimization can be generated to minimize CO_2 emissions using the same optimization methods.

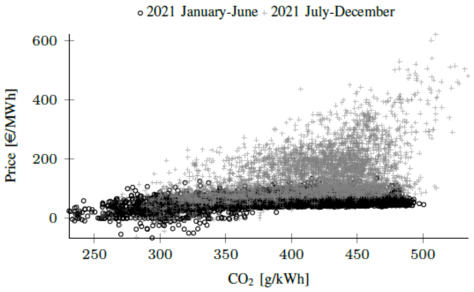

Fig. 2. Scatter plot of CO_2 emissions and Day-Ahead market prices.

In this context it is important to note that some slow reacting and polluting generators (e.g., coal-fired power plants) may sometimes accept financial losses if they can keep them running and recover these losses later. Therefore, a low day-ahead market price is not necessarily the result of abundant renewable energy generation. This can also be seen in the scatter plot in Fig. 2 in which no strong correlation between the CO_2 emissions and day-ahead price is present.

3) Peak reduction: Value can also be created by using energy flexibility to support the smooth operation of the main electricity grid and therefore support the DSO. One aspect hereby is to perform peak reduction, which generally results in better supply voltages, less losses and an increased life expectancy of grid assets [13]. Furthermore, by demand-supply matching the load on the grid can be reduced and thereby congestion problems can be avoided. This leads to reduced investments for the DSO and simultaneously provides capacity for the implementation of more renewables in the local grid.

III. USE-CASE MODEL

This section presents the model of the Aardehuizen community, together with the approach for sizing of BESSs to increase self-consumption of sustainable energy.

A. Present day situation

To assess the effects on the energy system of energy communities that optimally use their flexibility, a model is required. Within this work we use the DEMKit simulation and demonstration toolkit [13] to model the Aardehuizen community. This software follows a cyber-physical systems approach, meaning that a model of the individual physical devices is created. These models also capture technical constraints (e.g., availability of an EV), and user preferences and constraints (e.g., indoor temperature bounds). An EMS is modelled on top of this, for which several algorithms are available to optimally control the modelled flexibility for different objectives. For more details we refer to [13]. The optimization method and objectives are presented in Section IV.

Since detailed load profiles and general usage of existing devices is not available, artificial load profile data and usage constraints are generated using the ALPG [14]. To generate realistic profiles, information from the Aardehuizen community has been collected through surveys, personal communications, and public information. This results in load profiles and flexibility information for each of the 23 households for the time span of a whole year. Next to this, the DEMKit model also covers the existing rooftop PV installations, electric hot water boilers with buffer storage, washing machines and dishwashers. For solar irradiation, weather data was obtained from KNMI for the year 2021 for weather station Heino [15].

B. Integration of BESSs and EVs

One of the goals of the Aardehuizen community is to reduce the dependency on the grid connection by utilizing more of their own surplus generation of renewable energy. Therefore, an analysis is conducted using the Load Profile Analysis Tool (LPAT) [16], which decomposes an imbalance load profile into multiple sub-profiles, representing time-scales of interest. For each obtained sub-profile, an analysis is conducted to derive the requirements necessary for a storage device to handle that particular sub-profile. Specifically, the available data of a single Aardehuizen households' load profile is analyzed for the period April 2018 to March 2019, with May 2018 being replaced with May 2019 due to large data gaps. The load profile consists of smart meter data with a sampling frequency of one measurement every 10 seconds. LPAT is now used to create the sub-profile for short term (diurnal) storage requirements. For this a cut-off frequency of 1/1800 Hz is used, such that this sub-profile contains behaviour of the time-scale 15 minutes or less. The following storage flexibility requirements are derived: power requirements ranging from -2.7 kW to 8.7 kW and with a capacity of 3.9 kWh. Each house is equipped with a smart controllable BESS with aforementioned parameters in the model.

Next to this, three EVs and smart charging stations are modelled to add the desired car sharing concept. Each charging station has a power rating of 22 kW, such that they match the peak power production from the solar carport. The capacity of each EV is 42 kWh and EV charging transactions are generated using the ALPG.

IV. OPTIMIZATION AND SIMULATION RESULTS

This section presents the optimization method and objectives, together with the results.

A. Optimization methods

Within the approach, the goal is to optimize the overall *community power profile* $\vec{x} = [x_1, x_2, \ldots, x_N]^T$ for N future discrete time intervals according to an objective function $f(\vec{x})$. Here, x_t is the aggregated load for time interval t of a set of devices M within the community: $x_t = \sum_{m \in M} x_{m,t}$.

For the optimization, we use distributed optimization algorithms, where each device $m \in M$ has its own agent that optimizes the operation of the device based on steering signals. These algorithms are tailor made to the device classes and can be found in [17]. Within this paper we consider ideal device models i.e., the modelled boilers, BESSs and EVs have a 100% efficiency and are loss-free.

For the coordination among the devices we use the iterative Profile Steering (PS) heuristic [18]. It is an iterative steepest gradient descent algorithm that minimizes the Euclidean distance between a *desired power profile* $\vec{p}$ and community profile $\vec{x}$, i.e., we minimize $||\vec{x} - \vec{p}||_2$. Initially, each device $m \in M$ optimizes its own power profile $\vec{x}_m$ according to either a global objective function $f(\vec{x}_m)$ or local objective function $g_m(\vec{x}_m)$. Then, in an iterative process, each updates its *candidate power profile* $\hat{\vec{x}}_m$ by again optimizing for aforementioned local and/or global objectives, while satisfying constraints, which also may depend on the obtained community profile $\vec{x}$ from the previous iteration. Therefore also actions planned by the other devices are influencing this update. Each device sends the updated candidate profile to the PS coordinator, which subsequently selects the candidate profile that improves the global objective value the most. The associated device replaces its profile by this candidate profile $\hat{\vec{x}}_m$. The iterative process continues until no (substantial) improvement is made or a maximum number of iterations is used. Additionally, grid constraints may be imposed through the aforementioned steering signals. For this an upper bound b^+ and lower bound b^- are defined [17].

This results in a layered multi-objective optimization for objective functions f and g_m. Here, objective function f steers the overall community power profile towards a feasible and/or desired profile. Objective function g_m optimizes the device operation towards a local objective to ensure acceptable profiles for the end-users. For more details on the used algorithms, we refer to [17], [18].

For the use case, the following three optimization objectives have been formulated:

1) Energy cost minimization (CM): The devices minimize their operational costs (negative costs meaning profit) based on Day-Ahead market price vector λ_t:

$$\text{minimize } g_m(\vec{x}_m) = \sum_{t=1}^{N} \lambda_t x_{m,t} \qquad \forall m \in M.$$

For λ_t we use 2021 Day-Ahead clearing prices for the Dutch market [19]. Note that the devices propose their initial plan based solely on this local objective. However, PS can still be (forcibly) applied by the DSO in case of congestion [8] or to satisfy grid constraints [17]. In this case, the local minimization is influenced by the obtained community profile $\vec{x}$ such that new device profiles x_m satisfy the community level constraints, i.e.:

$$b^- \leq x_t \leq b^+ \qquad \forall t \in \{1, 2, \ldots, N\}.$$

2) CO_2 emission minimization (EM): In this case, the same formulation and method as with CM is used however, here λ_t represents the hourly CO_2 emissions stemming from the Dutch energy mix for 2021 [12].

3) Peak reduction (PR): Here, PS is used to coordinate the set of devices towards a global power profile that reduces distrbution losses and the import and export peaks with the main grid. For this, the Euclidean distance between $\vec{x}$ and $\vec{p} = [0, 0, \ldots, 0]^T$ is minimized, i.e.:

$$\text{minimize } f(\vec{x}) = ||\vec{x} - \vec{p}||_2.$$

B. Results

For the optimization and simulation study, we consider a full year of 365 days in 2021 using discrete time intervals of 15 minutes. Perfect knowledge concerning the future (e.g., prices, CO_2 emissions, and flexibility) is assumed. For optimization, a rolling horizon approach is applied where optimization is performed every 96 time intervals (1 day) for 192 intervals (2 days) in the future. Using the aforementioned objectives, simulations have been performed to quantify the potential of using the flexibility for the three performance metrics (lower is better):

1) total energy costs: $\sum_{t=1}^{N} \lambda_t x_t$ in [€];
2) total CO$_2$ emissions: $\sum_{t=1}^{N} \lambda_t x_t$ in [tonnes CO$_2$];
3) Euclidean distance: $||\vec{x} - \vec{p}||_2$ [W].

The simulation results of the current setup (denoted by *NOW*) and the future model (with BESSs and EVs as indicated in Subsection III-B) of the community are summarized in Table I, together with the results for an uncontrolled case (*NC*).

1) Unconstrained case: From the results in Table I it is clear that, as is to be expected, directly optimizing towards a certain goal (*PR, CM*, and *EM*) leads to the best achievable results on their respective performance indicators. Also, a clear gain is observed compared to the simulation without optimization (*NC*). With *PR* as objective, the strain on the grid is significantly reduced in comparison to *NOW* and *NC*, with *PR* the import (dependency) is reduced by 44% and the power peak by 29% compared to *NOW*. Optimization towards global incentives (prices or CO$_2$ emissions) in the futuristic case leads to high power peaks and significant import and export of energy. This is the result of the increased flexibility, which is used to its fullest potential, leading to large power peaks due to synchronized usage of flexibility (see Fig. 3). This phenomenon is also observed in literature [20]. Due to this, the cost can be reduced by €3824.36 (without taxes), or approximately €166 per household compared to *NC*. Noticeably, relatively high prices may occur at times of renewable generation from PV, leading to excessive production feed-in peaks that surpass the PV generation capacity by discharging of the batteries. Alternatively, 2.74 tonnes CO$_2$ emission can be avoided when using *EM*. It is clear that the Day-Ahead market prices do not correlate, resulting in a significant difference of €1665.86 and 2.51 tonnes CO$_2$ between *EM* and *CM*.

2) Constrained case results: As the unconstrained cases show excessive peaks, a simulation study is performed with *CM* and *EM*, where the DSO limits the capacity c in kW for each of the 23 households (*CMc* and *EMc*). As the PV carport has a dedicated connection, an additional feed-in capacity of -75 kW is added, resulting in $b^- = -23 \cdot c - 75$ kW and $b^+ = 23 \cdot c$ kW for the community. With $c = 1.5$, the limits are close the capacity that was historically used for grid design in the Netherlands, and therefore the situation found in many places. The results presented in Table I show that in both cases (*CM* and *EM*), this influences the performance on either cost or CO$_2$ emissions minimization significantly. Moreover, increasing the capacity to $c = 6.0$ does not significantly improve these figures. From the load-duration curves for different values of c in Fig. 4, we observe that a plateau is formed, using the available capacity for over 10% of the time, as depicted in Fig. 5. These results show that a substantial part of profit or CO$_2$ reduction, as observed in the unconstrained cases, is obtained in only a few time slots during the year, where all flexibility is

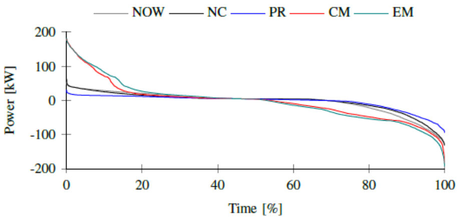

Fig. 3. Load duration curves for the unconstrained cases.

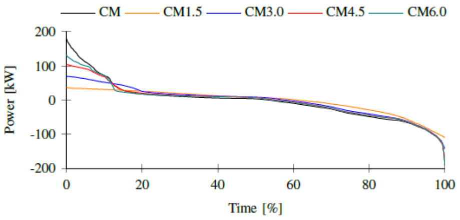

Fig. 4. Load duration curves for cost minimization (CM) with grid constraints.

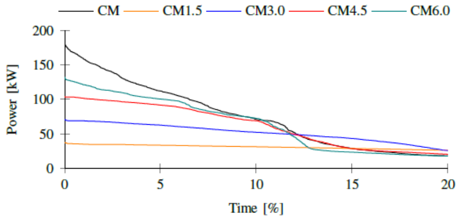

Fig. 5. Zoomed load duration curves for cost minimization (CM) with grid constraints.

C. Discussion

It has to be note that the used models have their limitations, such as loss-free storage and the absence of a degradation model and associated costs. Therefore, the current optimization behaves too greedily, and some effects probably will not be as pronounced as shown in this study. Furthermore, it is assumed that the influence of consumers on the national prices and CO$_2$ is negligible. Nevertheless, it gives an insight into the directions energy communities may move under the new legislation, especially if there is no equal playing field among stakeholders. The automated control of flexibility, combined with geographical clustering of communities, may lead to peaks that endanger the energy transition. If concerns of all stakeholders are not properly addressed in the design of upcoming laws, regulations, and frameworks, then the conflicting interests may as well lead to a deadlock, halting the energy transition. Especially if conflicting objectives, such as the strict and static constraints used in

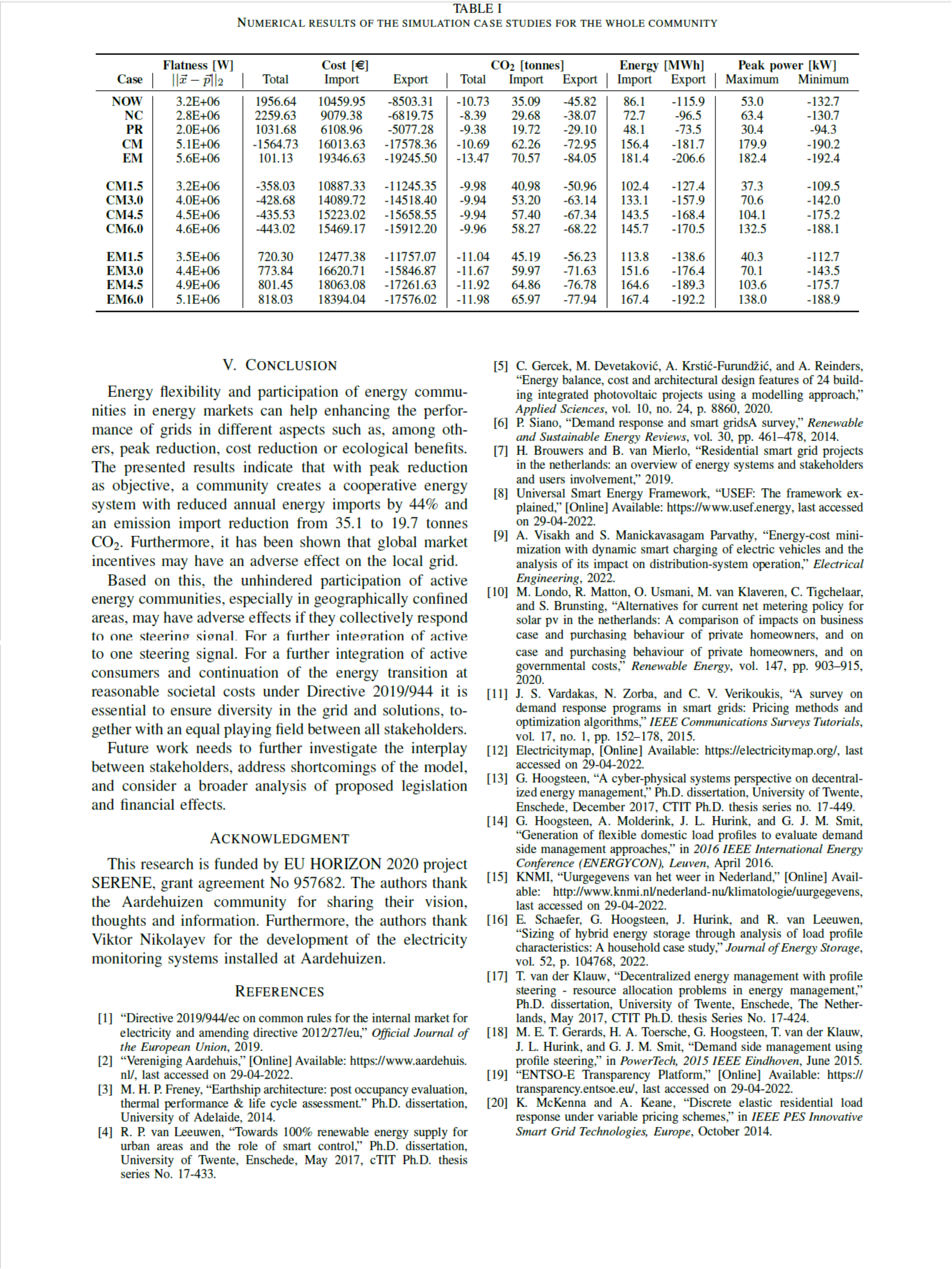

TABLE I
NUMERICAL RESULTS OF THE SIMULATION CASE STUDIES FOR THE WHOLE COMMUNITY

	Flatness [W]	**Cost [€]**			**CO$_2$ [tonnes]**			**Energy [MWh]**		**Peak power [kW]**	
Case	$\|\|\vec{x}-\vec{p}\|\|_2$	Total	Import	Export	Total	Import	Export	Import	Export	Maximum	Minimum
NOW	3.2E+06	1956.64	10459.95	-8503.31	-10.73	35.09	-45.82	86.1	-115.9	53.0	-132.7
NC	2.8E+06	2259.63	9079.38	-6819.75	-8.39	29.68	-38.07	72.7	-96.5	63.4	-130.7
PR	2.0E+06	1031.68	6108.96	-5077.28	-9.38	19.72	-29.10	48.1	-73.5	30.4	-94.3
CM	5.1E+06	-1564.73	16013.63	-17578.36	-10.69	62.26	-72.95	156.4	-181.7	179.9	-190.2
EM	5.6E+06	101.13	19346.63	-19245.50	-13.47	70.57	-84.05	181.4	-206.6	182.4	-192.4
CM1.5	3.2E+06	-358.03	10887.33	-11245.35	-9.98	40.98	-50.96	102.4	-127.4	37.3	-109.5
CM3.0	4.0E+06	-428.68	14089.72	-14518.40	-9.94	53.20	-63.14	133.1	-157.9	70.6	-142.0
CM4.5	4.5E+06	-435.53	15223.02	-15658.55	-9.94	57.40	-67.34	143.5	-168.4	104.1	-175.2
CM6.0	4.6E+06	-443.02	15469.17	-15912.20	-9.96	58.27	-68.22	145.7	-170.5	132.5	-188.1
EM1.5	3.5E+06	720.30	12477.38	-11757.07	-11.04	45.19	-56.23	113.8	-138.6	40.3	-112.7
EM3.0	4.4E+06	773.84	16620.71	-15846.87	-11.67	59.97	-71.63	151.6	-176.4	70.1	-143.5
EM4.5	4.9E+06	801.45	18063.08	-17261.63	-11.92	64.86	-76.78	164.6	-189.3	103.6	-175.7
EM6.0	5.1E+06	818.03	18394.04	-17576.02	-11.98	65.97	-77.94	167.4	-192.2	138.0	-188.9

V. CONCLUSION

Energy flexibility and participation of energy communities in energy markets can help enhancing the performance of grids in different aspects such as, among others, peak reduction, cost reduction or ecological benefits. The presented results indicate that with peak reduction as objective, a community creates a cooperative energy system with reduced annual energy imports by 44% and an emission import reduction from 35.1 to 19.7 tonnes CO$_2$. Furthermore, it has been shown that global market incentives may have an adverse effect on the local grid.

Based on this, the unhindered participation of active energy communities, especially in geographically confined areas, may have adverse effects if they collectively respond to one steering signal. For a further integration of active consumers and continuation of the energy transition at reasonable societal costs under Directive 2019/944 it is essential to ensure diversity in the grid and solutions, together with an equal playing field between all stakeholders.

Future work needs to further investigate the interplay between stakeholders, address shortcomings of the model, and consider a broader analysis of proposed legislation and financial effects.

ACKNOWLEDGMENT

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6 Social cost-benefit analysis of a local integral energy system in the residential area of Aardehuizen

A social cost-benefit analysis assesses all the impacts of a project and expresses them in monetary terms. Within this analysis both the market goods are considered as well as non-market goods (such as emissions, pollution, visual and audio nuisance). In the end this provides an overview of current and future pros and cons of a particular project (or investment) [37].

From the calculations for future situations made in section 4.2, it stands out that under different rate- and pricing systems there is always a profit to be made, at least as long as the community is seen as an economic unit. This raises the question if there are also social benefits if we consider costs and benefits from third parties and not priced or hard to praise goods. In this paragraph an attempt is made to create an overview of social costs and benefits for a local integral energy system, via a social cost-benefit analysis. This type of analysis assesses all the impact of a project and expresses them (as far as possible) in monetary terms. Furthermore, the beforementioned savings in emissions will also be expressed in a monetary value, as there are sources to support in valuing said emissions.

It is important to know that the future situations with battery and with external demand management as outlined in section 4.2 assume that the demand behaviour of the inhabitants is not changed.

When applying a social cost-and-benefit analysis in practice, choices have to be made in order to strike a good balance between methodical purity and practical feasibility. To substantiate this choice, attention must be paid to the following methodological issues.

Social cost-benefit-analysis can be made in various ways. At this moment four different approaches are explored:

1) Consumers and producers Surplus' with or without market shifts;
2) The market makes adjustments, whether or not quickly enough;
3) With external effects, it just depends on how far you want to go;
4) How to value taxes and allowances related to the trade in electricity.

1) Consumers and producers Surplus’ with or without shifts in the market.
If circumstances surrounding demand and supply vary, this will affect the supply and demand curves. Though these supply and demand curves reflect the wishes of consumers and producers at different prices, they are indicators of the fulfilment of wishes. From a methodological perspective, it is hard to draw conclusions, as one needs specific information about these curves. In general, there is the methodological difficulty of comparing consumer and producer surplus. It is the difficulty of the interpersonal utility comparison.

Because the amount of used electricity does not change, we do not have the methodological problem to value this change for the consumer side. The difference between the financial savings on electricity and the costs that must be incurred for participating in the system/variant is the only thing that counts. That difference can also be negative.

In addition to cutting energy costs, the system can potentially also become a new way to earn money. This opportunity arises when services can be provided on the balance market. These services mean that capacity is made available for electricity in exceptional situations in order to maintain the balance between supply and demand [38].

On the production-side however, there are variations in turnover and profit. This counts for the nationwide producer as well as the local producer. The national producer will sell less, and the local producer will sell more. Here too we are dealing with interpersonal utility comparison[3], but to keep it manageable, it is initially decided to offset these changes in profit to each other. Whereas in the future one could also think about (also theorized by Kumar et al. 2020 [40]) for example eliminating local unemployment.

However, if we choose to view the social cost-and-benefit analysis primarily from a regional perspective, a different choice may be made. For example, if people attach significant importance to solving local or regional unemployment, it may be that a job in the specific region is given more weight than a job elsewhere.

2) The market makes adjustments, whether or not quickly enough.
In the long run, everything is adaptable. This also applies to the electricity grid. In this respect, grid congestion cannot be assumed for long-term calculations. But if there is a capacity shortage on the grid 'in the interim', the Netherlands has the option of applying congestion management. Congestion management means that agreements are made between the grid operator and companies to accept lower usage at certain times for a fee. This fee, which can also be short on electricity bills, is an indicator of the social costs resulting from a capacity shortage on the grid.

However, in recent years the 'temporary' shortages on the grid have become so great that congestion management does not work properly or is not accepted as a structural solution[4]. New establishment and expansion of companies cannot continue because the capacity on the grid is not there. The shortages differ per region. In that case, the damage that must be linked to the failure of the grid, and vice versa the benefit of preventing shortages, concerns the economic development in a region in general. One could indeed try to calculate the value of this missed added value, but it in practice it is often too hard to do. One way to get an indication are the local or regional governments subsidies to solve grid problems with the augment of social-economic-policy. Then it is necessary to find the relation between euros of the subsidy and spared or created grid capacity. If this gets too complicated it is better to discuss the social economic problem qualitatively.

3) Environmental effects? It depends on how far you want to go (but there are other difficulties).
Fossil fuels have negative externalities at all (geographical) levels. On a global scale it concerns the greenhouse effect and depletion of fossil fuels in general (the question is whether you can still call that a problem in today’s climate), on a continental scale it is acid rain, on a regional scale one can think of nitrogen, and on a local scale fine dust and odours, not to mention the many problems with oil extraction in countries that are often far away from us.

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[3] The issue with not taking interpersonal utility comparisons into consideration is that the experienced monetary value is different for every person, based on their own preferences and situation. Hence the perceived impossibility of scientific interpersonal comparisons of utility (please refer to [39])

[4] Congestion on the grid is partly also a ‘paper issue’. In the Netherlands, the rule applies that for every household or company that is going to be connected, electricity-supply is guaranteed at all times.

CE Delft (2022) [41] provides an overview of the current divide (in the Netherlands) of the energy-mix, which can be seen in the table below.

Table 13: Emission-factors for production and supply chains of electricity production [40].

	Production	**Supply chain emissions excl. centres and means of production**	**Supply chain emissions from centres and means of production**	**Total**
Total electricity-mix (100%)	369 g/kWh	58 g/kWh	5 g/kWh	427 g/kWh
Grey electricity-mix (81%)	454 g/kWh	69 g/kWh	1 g/kWh	523 g/kWh

A complication is the fact that the power comes from a mix of sources. On the one hand, it is about the distinction between sustainable and fossil sources and nuclear energy. However, even within the fossil fuel category, there is again a distinction between more and less polluting variants. An additional complication is that the composition of the source's changes over the days and during a 24-hour period. In short, the negative externalities are extensive and hard to manage in a both a physical and a financial way. Fortunately, this study does not need to calculate these because other research institutions have done so before and from a technical perspective, assumptions have already been made. Since the 1970s, the Centre for Energy Saving in Delft has focused on this calculation.

CE Delft has looked at the intervention (for example emissions or nuisance & extraction), put them into midpoints (environmental themes), created endpoints to then assign value. A brief overview of this process can be seen in Figure 26.

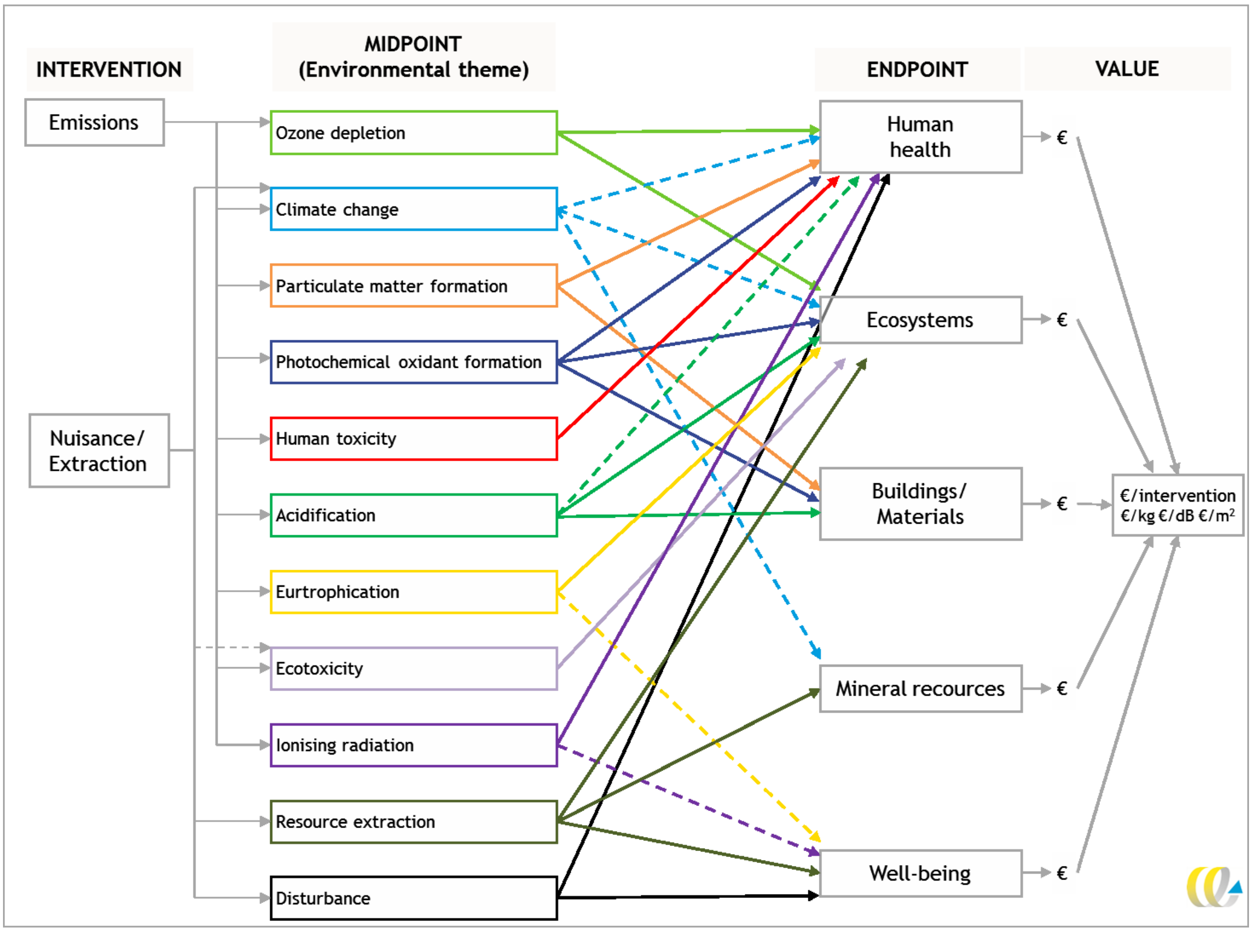

Figure 26: Intervention, Midpoint, Endpoint & Value[42]

The actual value of the emissions involved in this calculation can be seen in Table 14, where it shows an overview of environmental prices for average atmospheric emissions (based on the price per kg emission). There is a divide between the prices in the Netherlands and the EU, as a lot of the prices are similar, however some have differing costs [42].

Table 14: Environmental prices for average atmospheric emissions (€2015/kg emission).

Substance	Lower (EU)	Lower (NL)	Central (EU)	Central (NL)	Upper (EU)	Upper (NL)
Carbon dioxide *	€ 0,022	€ 0,014	€ 0,057	€ 0,057	€ 0,094	€ 0,057
Chlorofluorocarbons *	€ 130	€ 99,6	€ 306	€ 313	€ 504	€ 336
Ultra-fine particulate matter	€ 27,7	€ 56,8	€ 38,7	€ 79,5	€ 59,5	€ 122
Particulate matter	€ 19	€ 31,8	€ 26,6	€ 44,6	€ 41	€ 69,1
Nitrogen oxides	€ 9,97	€ 24,1	€ 14,8	€ 34,7	€ 22,1	€ 53,7
Sulphur Dioxide	€ 8,3	€ 17,7	€ 11,5	€ 24,9	€ 17,9	€ 38,7
Ammonia	€ 10	€ 19,7	€ 17,5	€ 30,5	€ 25,2	€ 48,8
Volatile Organic Compounds	€ 0,84	€ 1,61	€ 1,15	€ 2,1	€ 1,84	€ 3,15
Carbon Monoxide	€ 0,0383	€ 0,0736	€ 0,0526	€ 0,0958	€ 0,0918	€ 0,152
Methane *	€ 0,673	€ 0,448	€ 1,74	€ 1,75	€ 2,91	€ 1,77

* The value of greenhouse gas emissions includes VAT and increases by 3.5% per annum relative to the 2015 values (figures combined from [42]

There are further emissions and effects however, they are less relevant for the current case. One of the other relevant challenges is the case of visual nuisance, as it can impact welfare. With new developments an area might be reduced in terms of local environment quality, by blocking or changing views, or making it less attractive. Throughout the years this has been monitored and even valued (especially for windfarms) [43]. The degree to which visual nuisance is experienced depends on the height, shape, and size of the object. It also depends on how well the new development is consciously blended into its surroundings. This also makes it hard to value specific visual nuisance, as it is highly context specific. An example of visual nuisance affecting values can be found with windfarms, where the valuation of house-prices dropped near windfarms ([43], [44]).

There are some negative external effects of local sustainable energy production in production and during exploitation. At this moment it is difficult to make these calculations, however it is important to be aware off.

4) How to value taxes and allowances related to the trade in electricity

In addition to the value added tax (VAT/BTW) that also applies to other sectors, there are special taxes in the energy/electricity sector, such as the environmental tax and the tax for storage of renewable energy (ODE). Subsidies are provided for sustainable energy. This may concern investment grants as well as operating grants. These expenditures and receipts for governments must be included in a social cost-benefit analysis. Again, this brings forward the problem of interpersonal utility equations.

To summarise:

- Profit for the consumer: less expenditure for electricity, see paragraph 4.2. Furthermore, it was found that network services at this scale are not profitable [38].
- The decrease in turnover and profit because of a decrease in production, supplying and transporting 'nationwide' (above local) can under normal conditions (no shortages on the grid) be offset by the increase in turnover and profit at the local level. This valuation may be different if a contribution to local employment has to be extra high, because of local socio-economic problems. In that case you must put a societal premium on local profits (but in the technology-sector in the Netherlands in 2022 this is not so obvious).
- More turnover and profit for aggregator, but that does not matter in this specific case (as the project is not big enough to make it interesting and profitable enough for both parties to be involved).
- If congestion management can solve grid problems in the short run, then the possibility arises to consider fees for companies which are willing to reduce their level of required peak energy at peak times, by which they will contribute to relieving the congestion problems of the energy network.
- If congestion management cannot solve grid problems in 'the short run' period of grid shortage it is hard to calculate the economic societal losses of grid shortages. Some municipalities have shown by giving allowances how they value the preventions of these shortages. If this in the specific circumstance is not a practically feasible method, it is better to discuss this effect qualitatively. Several sources [45], [46], [47], [48] acknowledge this issue, and point out that there is currently no specific metric of value available. They also note that the prices on the congestion-market are highly uncertain and depend on ruling of the ACM (Authority of Consumer & Market).

Furthermore, it is known that the costs for congestion-management are currently being divided over all users, so lower costs will directly create societal benefits [48].

- On balance, fewer negative external effects related to the environment. You can put a fair price tag on this. Key figures are known via [42]. In the calculations which were made in the *Environmental Prices Handbook* there are valuations in relation to CO2-output. Assumptions are made about part of fossil and the composition of fossil in relation to the total electricity production.

For a quantitative (monetary) societal cost-and-benefit-analysis of a local integral energy concept in this study, what is realistic to include?

Table 15: Realistic factors to include in the current situation SCBA

Social Benefits and costs	Physical	Monetary
Less expenditure for electricity by inhabitants	See paragraph 4.2	CE and other sources
Extra earning by inhabitants because of grid services	See paragraph 4.2	Too small scale, potential transaction costs would be higher than extra earning.
Extra profits for firms	See paragraph 4.2	Set off to each other, and the aggregator has no business case, see above
Lowering negative external effects	It is in the article, in first instance our attention go out to CO2	
Government earning (properly negative)		It is the sum of all governments expenditures and revenues
Contribute to lowering net scarcity	See paragraph 4.3	Net congestions fees, Fees for accepting temporarily lowering power connection

A comparison between the new situation: control, battery and 3 EV's versus the current situation: no control, no battery and no EV's at fixed rates.

Table 16: Comparison between the current & new situation.

Social benefits and costs	Physical	Monetary
Less expenditure for electricity by inhabitants.	Cannot be determined at this time.	Per household: 1136 – 1069 = 67 euros of saving. 23 * 67 = 1541 of total saving.
Extra earning for inhabitants because of grid services.	None.	None.
Extra profits for firms.	None.	None.

Lowering negative external effects.	13,4736 – 10,7827 = 2,7449 ton less CO^2 emission.	(2,7449 * 57 euros) * 1,317 = 205,42.
Government earning (properly negative).	None.	The netting method means that there is no effect on government tax receipts.
Contribution to lowering net scarcity.	(Until) now not to determine from the research.	Contribution to lowering net scarcity cannot (yet) be determined and deduced from the data. Associated amounts of money based on capacity limit contracts require further study. The same counts for local or regional government grants.

Acceptance

Beyond the costs and benefits there is also an important analysis to be made about the acceptance of the new developments. Acceptance is a concept that involves a reaction to something which is proposed externally. Within this, acceptance can be seen as a positive attitude towards the proposed change. Furthermore, acceptance that only covers an attitude of support can be described as ‘tolerance’ rather than true acceptance [49]. The following section is about the acceptance of the system.

It is important to consider that it is not just about the acceptance of the inhabitants of the Aardehuizen community in this specific situation. Ideally, the aim is to see to what extent the situation at Aardehuizen can lead to a general model of acceptance of local adaptations to reduce the electricity consumption for the community from a financial and social perspective.

Leiren et al. (2019) [50] mention that there are six factors that standout when it comes to community acceptance for Sustainable Energy projects (e.g. Wind energy projects, Solar energy projects, etc.):

- Technical characteristics (e.g. the size and numbers);
- Environmental impacts (e.g. impact on the physical environment, biodiversity and wildlife, and emissions);
- Economic impacts (e.g. local profits and income generation);
- Societal impacts (e.g. effect on human health, wellbeing and quality of life);
- Contextual factors (how the environmental, societal and economic impacts are perceived and valued);
- Individual characteristics (e.g. socio-cultural values, sense of place, self-identity, place attachment, discourse in the public sphere, and the political climate).

What stands out is that policy and corporate measures might have an influence over how relevant the impacts are perceived by the participants [50].

In the present study, the choice was made to put the technical system (battery plus control mechanism) first. The basic principle is that the technical adjustments made when residents participate do not influence behaviour. In addition, the investments in solar panels have already been made before. The ownership of solar panels, in the current situation, seems to be in one party (which for full clarity has to be explored). Furthermore, participation in the new system (battery plus external control) by the residents does not cost anything, which removes one of the possible barriers, namely one side of the economic factors.

The offer made to the residents seems to be an offer that you cannot refuse. After all, they do not have to give up anything, it costs them nothing and it lowers the electricity bill.
However, it turns out that not everyone is on-board. 'Only' fifteen of the 23 families are participating. This could be even more in the current energy climate, yet the question remains: Why would the others not want to join? Ferdi Hummelink (spokesperson for Aardehuizen) has outlined in an email what he thinks the conditions should be to take into consideration, under which residents would like to participate.

The current motives and desires of the inhabitants of Aardehuizen can be summarized as follows (to a greater or lesser extent, depending on the individual):

- It should be easy: Do not ask for too many (daily actions);
- It must be understandable (unknown makes it undesirable);
- It must be voluntary, so also provide the space to (temporarily) not participate;
- It should save energy;
- It must increase autonomy (less electricity traffic outside of the district).

Later, a meeting will be planned with Ferdi Hummelink (representative of Aardehuizen), about the extent of substantiated information that is available (or has to be collected) about the wishes of the inhabitants, whether there are notorious dropouts, etc. Besides this an extensive survey will take place in a later phase of the project. The survey will then not only focus on the acceptance of the present system, but will also investigate the wishes of systems based on influencing behaviour.

As for the users of the EV chargers. It does not really matter whether the users come from inside or outside the district. It is most important to look for a rate at which it is favorable to use this charger. With this there is a fine balance to explore the optimal situation in regard to low transaction costs, which would indicate long-term contracts, yet keeping some flexibility, which is also desirable given the volatile nature of the energy market.

7 Conclusions

This report demonstrated the financial benefits of smart grid systems and flexibility, in terms of reliability, cost against other alternatives and participation in local flexibility and grid resilience (peak shaving). Financial benefits for citizens and local energy communities were kept at its centre, an average electricity bill was calculated for many scenarios and infrastructure to indicate the right solutions. The technical designs, the conditions of implementations, and technical work that allows the business cases is also detailed.

The economic and ecological sustainability, local involvement and potentials and avoided costs are defined for numerous pricing methods. DSO's or Local spin offs could take part shaping the local energy transition together with energy cooperations, to help the national grid in transition. The scenarios and cases that mapped current situation in households, also provided dynamics of the different Dutch pricing mechanisms under different optimisation and scenarios. This made the consequences of optimisation priorities more tangible in terms of electricity bills and finances.

From the financial dynamics described, the roles of other actors involved such as DSOs, Spin offs, e mobility, are ready to be elaborated for the concrete Dutch demonstrator cases, as input to other work packages. The social cost benefit analysis chapter introduced the smart energy systems implications and benefits of the society. How those different partners could concretely take part, their roles and their potential business models will be further detailed in D3.4 from a social innovation and business models perspective.

The Dutch energy sector, and residential prices, are highly changeable at this moment. The Government has established a price cap at the end of September 2022 during the writing of this report. Yet for 2023 prices this price cap is announced to be halved for a range of small electricity consumers (kleingebruikers). This is done to protect the Dutch civilian right, access to energy. Yet, it is unclear how and which funding scheme will be applied precisely in 2023. Several questions arise its implications, rather it will be applied to all tariffs including dynamic tariffs. If price cap is also applied for dynamic pricing, smart gird algorithms and dynamic pricing might even become more advantageous than reported here. Yet as these developments occurs simultaneous to the redaction of this report, further investigation on that topic would be needed for specifically dynamic pricing scheme.

This report depicted the great opportunities ahead to energy communities and prosumers of the Netherlands. With their avoided costs, they could invest in greener technologies, thus contribute to the green energy transition.

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9 Annex A

Annex A. Battery providers

Battery systems Weighting Factors

Supplier	Type	per kW	Price € per kWh	TRL	Enviromental	Inverter compatibility	°C	Com.	Warranty	System kW	kWh	total price	Cycles	Dept of discharge
Kiwatt	LiFePO4	2000	1000	7		SMA	?	Very good		20	40	40k		
Nilar	Magnese	1140	600	7	recycable	DC-DC	-10 _ 40	Good-Implicit	1 year		10	6k		
Greenrock	Seasalt	4000	1000	7	recycable		0_ 50	?	??	8	40	32k	5000	80%
ecaraccu	Li ion	1600	1100	8	2nd hand				3 years	70	100 (64 min)	110k	less	less
sunwatts	Lead acid		1555	7							113	31k	1800	50%
Litech Powre	LiFePO4	520	455	8										
Huawei Large	LiFePO4	830	400	9	RoHS6	included	-20 _ 60	ModbusTCP	5 years					
Huawei Home	LiFePO4	840	420_ 510	9	RoHS6	included	-20 _ 60	RS485/CAN	5 years	5_7	5 _ 15			100%
Tesla Powerwall	Li ion	1700	850	9	RoHS directive 2011/65/EU		-20 _ 50		10 years					
LG RESU 10	Li ion	1140	568	9	RoHS		`-20_45'	SMA compatible, Can 2.0B						
BYD	Li ion		560	9					10 years					

Annex B. Detailed results of the flexibility simulations for the Aardehuizen demonstrator for the current and future situation

	Peakshaving	Cost [€]	Cost Imports [€]	CO2 (tonnes)	CO2 (import (tonnes)	Import [kWh]	Export [kWh]	Max Peak [kWh]	Min Peak [kWh]
Current Situation									
No Control	3166070,309	1956,638	10459,95237	-10,7287	35,0932867	86102,96	-115882,5066	53042	-132698
Peak shaving	2521703,625	897,0038	7826,690207	-11,6592	26,7059178	65686,49	-96986,951	21367	-108352
Cost Min	2965474,22	110,0016	8696,240009	-12,1973	32,11722624	80100,58	-111349,5284	55982	-128408
CO2 min	3090317,261	551,0684	9283,093111	-12,9589	33,24031179	84629,96	-115931,9078	56993	-129441
Future Situation									
No Control	2792350,831	2259,63	9079,383118	-8,39143	29,6802207	72654,18	-96462,82767	63446	-130681
Peak shaving	2021944,669	1031,679	6108,961029	-9,37875	19,72487665	48105,15	-73507,62181	30389	-94282
Cost Min	5128820,297	-1564,73	16013,6341	-10,6925	62,25846236	156413,2	-181686,9201	179929	-190238
CO2 min	5613593,624	101,1304	19346,63354	-13,4736	70,57463848	181404,3	-206646,1168	182405	-192419
With import limitations: Current Situation									
Cost Min	2613471,4	911,6009	7950,267738	-11,598	27,33206449	67308,98	-98372,268	32690	-125448
CO2 min	2620376,727	970,8337	8005,067757	-11,6963	27,3311797	67551,43	-98604,004	31825	-120287
Future Situation									
Cost Min	2320907,206	1024,453	6275,44916	-9,38014	20,5769863	50373,54	-75568,29033	29577	-178161
CO2 min	2490951,995	1151,094	6376,165824	-9,63238	20,91764762	51363	-76480,96737	35178	-183601