Eindhoven University of Technology
System integration project

Current opportunities for PV-Systems on apartment buildings in the Netherlands, and solutions to increase self-consumption of solar electricity.

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Executive Summary

The installation of a photovoltaic (PV) system on apartment buildings is challenging, since it comes with a number of legal and administrative hurdles. It is hard to get a good overview of the technical possibilities, the legal boundaries, and financial incentives related to the installation of such a system. Moreover, the involvement of many parties poses another challenge. Further, the uncertain future of the net-metering scheme, presently the primary tool of the Dutch government to stimulate the implementation of local electricity generation, is a concern for homeowners interested in purchasing solar panels. If the net-metering is phased out, the self-consumption of locally generated energy becomes important.

This report presents the results of a research conducted by a student team from the Technical University of Eindhoven (TU/e) in cooperation with the association Veldhoven Duurzaam. Two main questions are analysed in this paper. First, the current situation related to the installation of a PV-system on a apartment building is analysed, namely the legislation, subsidies, and technical possibilities, which are involved. This analysis has to be performed in order to give recommendations to home owners associations (VvEs) about what the best solutions for installing a PV-system are at the moment. Secondly, the possibilities to increase the self-consumption of locally produced electricity are analysed, in order to find solutions to make PV-systems as profitable as possible in a future without net-metering.

During the research about the current possibilities for installing a PV-system on the roof of an apartment building, it was found that there are different possibilities to connect such a system. The system can either be connected to the communal utilities connection of the building or it can be connected to one or more individual apartments. Moreover, a combination of both connections is possible. Further, there is the possibility to install a small system on a balcony or rent the roof to an external company, who will place solar panels on the roof to exploit them. Different subsidies are available depending on different criteria like the system size or the connection type. Five implementations of a PV-system were identified: a collective PV-system for communal utilities making use of the SCE or SDE++ subsidy, a collective PV-system for participating owners, a PV-system for individual (Balcony) use and a PV-system for non-private use (rented roof). For each of these implementations the available subsidies and loans, the legal steps and the technical implementations were examined. Next, a model, based on a cost benefit analysis, was build to compare the net present value (NPV), internal rate of return (IRR) and payback period (PBP) of the different PV-system implementations. These implementations were simulated for six reference buildings of different sizes. The overall ranking of the implementations were the same for these six buildings. It came out that the collective PV-system for communal utilities making use of the SCE is the best option for the VvE, because it has the highest IRR and the lowest PBP. However, when enough space is available on the roof, a combination of a collective PV-system with SCE and participating owners generates more profit in absolute terms (higher NPV), while the IRR and PBP are lower. Furthermore, a sensitivity analysis showed that after 2023 with every year, that the investment in a collective PV-system for participating owners is delayed, the NPV is reduced with 1.82% and the IRR with 0.34%, because of the phasing out of the net-metering scheme. Moreover, it was found that variations in the self-consumption have moderate effect on the commercial viability of the project and fluctuations of the correction amounts of the SCE have little effect on the NPV. It can thus be concluded that, even though it is beneficial, an increased self-consumption is not necessary for a PV-system to be profitable in the future. Lastly a road map was made, where the results of the simulation model are incorporated in a flow chart. A VvE can answer the questions in the flow chart resulting in the most suitable PV-system implementation (See Appendix D).

During the research on solutions to increase the self-consumption, it was found that there are two ways to increase this value, namely by using local energy storage or by using load shifting. A number of technical solutions for both storage and load shifting are already available, however, a lot of the potential of these solutions cannot be used, because the necessary regulations are not in place yet. For example the current tariff structures do allow the shared use of battery storage by more households, or the use of a smart grid with several parties, besides for a few experimental installations. Nevertheless, six solutions to increase the self-consumption within an apartment building, were identified, that are compatible with the current situation. It was found that the solutions involving battery storage investigated here, are not yet financially lucrative with the current battery prices. Further it was found, that a local load management system for an apartment is not profitable for the case analysed in this research. The installation of a heat pump for the

apartment building was also identified as not profitable for the analysed case. Only the installation of electric vehicle (EV) charging stations that are accessible to the public was found to be a solution that increases the profitability of a solar system. Apart from financial aspects, the project group also analysed environmental, practical, and health and safety aspects related to the different measures. These were brought together in a multi-criteria-analysis, where the installation of EV charging stations was identified as the most promising solution.

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$a_{ii'}$	Dominance score of alternative i over alternative i'	
$_c$	Subscript when term is specifically for communal facilities	
$C_{reduction}$	Revenue due to money not spent on electricity	€/Year
C_{feed}	Revenue due to electricity sold to the grid	€/Year
C_{nm}	Subsidy received from the net metering scheme	€/Year
C_{SCE}	Subsidy received from the SCE	€/Year
$CF(s)$	Yearly cash flow	€
e_{ji}	Standardised data of criterion j and alternative i	
E_{gen}	Generated electricity by the PV-panels	kWh/Year
E_{self}	Self consumed electricity	kWh/Year
E_{nm}	Generated electricity that is eligible for net metering	kWh/Year
E_{feed}	Generated electricity that is fed back into the grid	kWh/Year
E_{con}	Consumed electricity	kWh/Year
$_h$	Subscript when term is specifically for households	
i	Interest rate	%
n	Index of years past initial operation	
p	Yearly inflation	%
r	Discount rate	%
SC	Self-consumption	%
w_j	Weighing factor of criterion j	%
$\%_{degen}$	The yearly degradation percentage of the PV-panel efficiency	%
$\%_{eligible\,nm}$	The percentage of electricity fed in to the grid that is eligible for net metering	%

Glossary

C-rate Measure of the rate at which a battery is discharged relative to its maximum capacity. A C-rate of 1 corresponds to the battery full discharging in 1 hour.

Cycle life The complete charge/discharge cycles that the battery is able to support before that its capacity falls under 80% of it's original capacity.

Depth of Discharge Fraction of the total electrical charge stored in a battery that can be extracted.

Net metering scheme A billing scheme where prosumers can subtract the energy they have generated from their energy bill. Dutch: salderingsregeling.

Nominal voltage The reported or reference voltage of a single cell in a battery. This is dependent on the anode and cathode materials used. Isn't necessarily the same as the operational voltage.

Prosumers An active energy user who both produces and consumes energy from renewable sources.

Round trip energy The ratio of energy put into and taken out of a storage system.

Self-discharge Reduction of the charge inside a battery without being connected to a load.

Acronyms

BTW Belasting Toegevoegde Waarde.

CBA Cost Benefit Analysis (Ducth: Kosten-batenanalyse).

DMS Demand-side management.
DoD Depth of Discharge.

EIA Energie-Investeringsaftrek.
EV Electric vehicle.

GHG Greenhouse gas.

IRR Internal rate of return (Dutch: Interne-opbrengstvoet).
ISDE Investeringssubsidie Duurzame Energie.

KIA Kleinschaligheidsaftrek.
KOR Small Business arrangement (Dutch: Kleine Ondernemers Regeling).

MAS Multi-agent system.
MCA Multi Criteria Analysis.
MIA Milieu-Investeringsaftrek.

NOM Nul Op de Meter.
NPV Net Present Value (Dutch:Netto Contante Waarde).

ODE Opslag duurzame energie (Dutch environment tax).

PBP Payback Period (Dutch: Terugverdientijd).
PV Photovoltaic.

SCE Subsidieregeling Coöperatieve Energieopwekking.
SDE Stimulering Duurzame Energieproductie.

V2H Vehicle to home technonolgy.
VAT Value Added Tax.
VvE Homeownners association (Dutch: Vereniging van eigenaren).

ZEP Zeer Energiezuinig Pakket.

1 Introduction

More and more households are deciding to contribute to a greener energy future by installing photovoltaic (PV) systems on their homes. However, this appears to be a greater challenge for apartment residents than for people who live in different type of housing. Research shows that less than one percent of apartment buildings in the Netherlands are equipped with a PV-system, compared to over ten percent of detached houses [1]. However, 15 percent of all homeowners in the Netherlands live in an apartment [2]. This discrepancy is mainly due to the fact that the installation of a PV-system on an apartment building involves many more administrative and legal hurdles than installing such a system on a single-party private home.

Another challenge associated with PV-systems is the uncertain future of the net-metering scheme. Net-metering has been the primary tool of the Dutch government to stimulate the implementation of local electricity generation. However, the Dutch government has proposed a bill to slowly phase out the net-metering scheme, starting in 2023 [3]. This means that the financial attractiveness of PV-systems might decrease in the future, as netting is a large part of the earnings model of this system. As a result, the application of other methods to make PV-systems economically attractive will play a greater role, also for apartment complexes. Especially the self-consumption of locally produced electricity becomes important, if the price of electricity purchased from the grid is significantly higher than the feed-in tariff for electricity sold to the grid.

The client of this research assignment is Veldhoven Duurzaam, a voluntary organization that aims to assist residents of Veldhoven in making their homes more sustainable, by sharing their knowledge about sustainability. The organizations is, among other things, concerned with the two problems stated above. On behalf of the organization, a student team called PV TUgether from the Eindhoven University of Technology carried out this research during the six-month long System Integration Project Graduate School course.

The aim of this paper is to propose and compare different possible implementations of PV-systems for apartment complexes, allowing apartment occupants and homeowners associations (VvEs) to make more informed decisions regarding the installation of such a system. In addition, various options for increasing self-use of generated solar energy are investigated and compared, allowing interested parties to determine whether PV-systems are economically feasible for apartment complexes when the net metering scheme is phased out. The research questions and the associated sub-questions investigated in this study are as follows:

1. What are the threats and opportunities regarding economics, technicalities and regulations concerning photovoltaic systems for apartment buildings?
    1.1 What are the rules of a VvE, related to making use of the roof and a shared grid connection?
    1.2 What are the current regulations and subsidies for installing and using PV-systems?
    1.3 How can the distribution of the generated solar energy be organised within an apartment building or complex (technically and financially)?
    1.4 How can the results of this research be put into practice? A road map to help VvEs in their decision-making process will be designed.
2. How can homeowners or groups of homeowners maximise the self-usage of electricity produced from a PV-system, in order to increase financial benefits, when/if the net metering scheme will be phased out?
    2.1 How does the future of the net metering scheme look like?
    2.2 What technical solutions are available in the near future to increase self-usage?
    2.3 What are the financial, environmental, practical and safety considerations related to the available solutions?

The report is organised in two parts, related to the two main research questions. The first part aims to provide insight into the current options and regulations regarding the installation of PV-systems on apartment buildings. The result of this research question is a road map, in which VvE's can find all the necessary information for installing a PV-system in a clear and structured manner. In order to reach this result, a literature search is conducted on the current regulations regarding residential PV, as well as regulations for VvE's. In addition, different system categories are defined and simulated for different apartment complex example cases. The results of the simulation model is used as an input for the road map.

The second research question relates to the phasing out of the Dutch net-metering scheme. A literature research was carried out to get insights into the future of the net-metering scheme and into the possible solutions to increase the self-consumption of electricity produced by a PV-system. The most promising solutions are assessed in a multi-criteria analysis (MCA), for which, among others, a financial analysis, including the modelling of the respective systems and an environmental analysis are carried out.

The scope of this paper is limited to the Dutch municipality of Veldhoven, since Veldhoven Duurzaam mainly operates in this area. The findings, however, may be applicable to other parts of the Netherlands. Additionally, this research is aimed at apartment buildings, as this is in line with the current interests of the organization. Moreover, the paper is limited to solar energy generation for a single building, so no connection and co-generation between different buildings or different energy generation methods are considered. For the calculation the current electricity prices are used since the prediction of future electricity prices is very complicated or even impossible.

The next chapter of this paper provides an overview of the conclusions and recommendations from this study. The literature review based on the descriptive sub-questions, the methodology and results of the quantitative sub-questions can be found in the appendix of this paper.

2 Conclusion and recommendations

In order to answer the first research question, both a literature research and simulations were conducted. To provide an overview of the current possibilities for installing a PV-system on an apartment complex, firstly the rules and regulations of VvEs, as well as the current regulations, subsidies and other financial incentives from the Dutch government and municipalities were described. A more detailed description of this literature overview can be found in Appendix A.1.

Secondly, five different PV-system categories were discussed: The first is a Collective PV-system, which generates the electricity for communal utilities and makes use of the SCE subsidy or in the second category makes use of the SDE++ subsidy. The third category is a Collective PV-system for participating owners, where the solar panels are wired to the participating apartments. The fourth category is a PV-system for individual use, which can be placed on a balcony or terrace of an apartment. Lastly a PV-system for non-private use, where the roof is rent to a energy company, which will install solar panels on the roof.

These five different PV-system categories, suitable for apartment buildings, were presented and analysed regarding their technical, legal, and economic feasibility. The advantages and disadvantages of these systems are very case specific and no 'best solution' could be named from the conducted literature research. Therefore, a model based on a cost benefit analysis (CBA) was built and calculations were made for six existing apartment complexes. The data for these existing apartment complexes was provided by Veldhoven Duurzaam and Compagnon Vastgoedbeheer. The cost and specification of a PV-system for communal use and a PV-system wired to all the participating apartments were obtained from an offer of 365zon.nl.

The ranking of the five different PV-system implementations, where the same for the six apartment buildings that were analysed. The collective PV-system for communal utilities making use of the SCE was indicated as the best. According to the model, it has the highest Internal Rate of Return (IRR) and the lowest Payback Period (PBP), however the Net Present Value (NPV) is the third best. The combination of a collective PV-system for SCE and participating owners generate the second best NPV, IRR and PBP. A VvE could still opt for this implementation if there is enough space available on the roof, to cover the communal utilities and some apartments, because it has a higher total profit, against a lower IRR and higher PBP, than the communal use only. The collective PV-system for participating owners has the highest NPV. However the IRR and PBP are third best due to the higher investment costs, which make the implementation less interesting.

A different revenue calculation was made for the PV-system for individual use and PV-system for non-private use. They are less favorable and should only be chosen if the roof of the building may not be used or the VvE/participants do not want to invest in a PV-system themselves. The ranking of the different implementations can be seen in Table 1. A more detailed explanation of the model and results can be found in Appendix A.2 and A.3 respectively.

Table 1: Ranking of different PV-system implementations

Solution	**Ranking**
Collective PV-system for communal utilities making use of the SCE	1
Combination of a collective PV-system for SCE and participating owners	2
Collective PV-system for participating owners	3
collective PV-system for communal utilities making use of the SDE++	4
PV-system for non-private use	5
PV-system for individual use	6

Furthermore, a sensitivity analysis was performed to see what the influence is of the initial year of operation on the results of the collective PV-system for participating owners, because net-metering will probably be phased-out from 2023 to 2031. With every year that the project starts later, the projects net present value declines with 1.82% and the internal rate of return with 0.34%. In addition to this, a sensitivity analysis was done on the self-consumption and the SCE correction amount in order to see how a variation in the input changes the results. It was found that the self-consumption has moderate effect on the commercial viability of the project. And the correction amounts of the SCE have little effect on the NPV.

Lastly a road map was designed, where the results of the simulation model are incorporated in the flows within the flow chart. A VvE can answer the questions in the flow chart and thus find the most suitable PV-system implementation. Moreover, when the VvE has found the most suitable PV-system implementation, one can see on the second page of the flowchart what kind of legal steps they should take to get permission to install the PV-system and a description of the subsidy they can make use of when choosing the relevant implementation. The road map can be found in Appendix D.

The second part of the report focuses on the possibilities to increase the self-consumption of electricity that is produced locally by a PV-system. The reason that this is investigated, is that the future of subsidies regarding PV-panels in the Netherlands is uncertain. Starting in 2023, the amount of electricity fed into the grid eligible for net-metering will be phased out in increments of 9% every year. It's still unclear what program will replace the net-metering scheme. The self-consumption, which is the percentage of the totally produced electricity that is locally consumed, will then gain in importance. The reason for this is, that electricity bought from the grid will be more expensive than what the electricity fed into the grid can be sold for.

The self-consumption is generally low, because the production is highest during the day when the sun shines, while the consumption is generally highest during the evening hours. From the literature research it was found that there are essentially two possibilities to increase the self-consumption of a household that has a PV-system. The first possibility is energy storage, which allows for the electricity produced during the day, to be consumed at a later time, when the production is lower than the consumption. The other option is load shifting, which means that the time of use of a load is changed in a way to match the production.

The most relevant storage solutions that were identified, are electrochemical battery storage and thermal energy storage. Especially Li-ion batteries, because of their low costs per cycle, and hot water storage are common. Battery storage is used to store the electricity from the PV-system directly and use it at a later time. For thermal energy storage, the electricity is first converted to heat, by an electric boiler or a heat pump, and then stored. This heat can later be used for space heating and/or domestic hot water (DHW) needs. The heat is not converted back to electricity. Both types of storage are already commercially available, and can be purchased by home owners.

Load management solutions were found to be applicable at different scales. Theoretically, they can be applied at grid level, neighborhood level or household level. One popular principle for load management is the smart grid technology. In such a system, every consumer and producer acts as an agent, who submits bids to purchase or sell electricity. The bids express the willingness to consume or produce of every agent for a certain electricity price. Using the principle of demand and supply, the price varies depending on the current bids, and thus the demand and supply are matched. However, it was found that it is unlikely that this technology will be applied at a large scale in the near future, because the necessary regulations and tariff structures for smart grids on grid or neighborhood level are not in place yet. For this reason the focus was put on load management solutions on household level.

It was found that the potential of load scheduling in a household depends on the number of programmable loads, which are loads that can be shifted in time. Examples of such loads are washing machines, dryers or dishwashers, because these types of loads do not necessarily need to run at a specific time during the day. More programmable loads result in a potentially higher self-consumption. Further, some large loads that are traditionally powered by fossil fuels, are being replaced more and more by electric loads. For example electric cars can be an alternative to traditional cars, or a heat pump can be an alternative to a gas fired heating system. Literature shows that the introduction of these large electric loads can also significantly improve the self-consumption.

The details of the literature research, regarding the future of the net metering, the storage solutions and the load shifting solutions can be found in Appendix B.1.

In the next step, six solutions to increase self-consumption, that can be implemented in an apartment building, were identified and compared in an MCA. The solutions were applied to a specific building with a specific PV-system, in order to have input values for certain calculations. An apartment complex analysed in the first part, that has 87 apartments and 5 buildings was chosen. According to the outcomes of the CBA, a PV-system as large as the roof allows is used, which is connected partly to the communal utilities and partly to, in total 15 of the 87 apartments. With this configuration, the yearly annual utility consumption and the consumption of the 15 apartments almost equals the annual production of the solar panels. The methodology of the MCA is described in more detail in Appendix B.2.

The alternatives compared in the MCA are solutions to increase the self-consumption of one apartment as well as to increase the self-consumption of the communal consumption. In order to compare these solutions, all the calculations are made for the entire complex, assuming that every connected apartment implemented the respective solution. The solutions for a single apartment are the installation of a Li-ion battery, the installation of a salt-water battery, or the use of a commercially available load management system with the brand name Smappee. The solutions for the communal consumption are the installation of a communal Li-Ion battery, the installation of a heat pump, or the installation of publicly available EV-charging stations, that are connected to the communal connection.

The six alternatives were scored on the basis of economic, environmental, practical, and health and safety criteria. In total 4 quantitative and 8 qualitative criteria were assessed. The criteria and the weights used for the analysis, can be found in Table 23 in Appendix B.2. The investment costs and the potential increase of self-consumption (not a criteria in itself, but used as an input for calculations) for each solution were determined form literature. The IRR and PBP of the solutions were calculated using a slightly adapted version of the financial model created to answer the first main research question. This model gives as a result the IRR and PBP for a project that includes the investment for a PV-system and for the respective solution, and not for the solution alone. It is important to note that only the EV-charging stations turned out to generate a higher IRR than the base case with no measures to increase self-consumption. The emissions saved by each solution were estimated by a calculation, and the qualitative criteria were assessed by looking at literature. The details on how the data was exactly collected can be found in Appendix B.3, and the final scores attributed to all the solutions and all the criteria are presented in Table 26. Finally a ranking of the solutions was determined which is presented in Table 2.

Table 2: Ranking of solutions

Solution	**Ranking**
Electric vehicle charging stations	1
Load management	2
Li-ion Battery (per apartment)	3
Central heat pump	4
Li-ion battery (communal)	5
Salt water battery	6

Before making final conclusions about the ranking, a stakeholder analysis was conducted, in which two additional sets of weighing factors were used, to represent different stakeholders. One set of weights provided by the project partner and one set of weights representing a very environmentally conscious home owner were used. The only alternative that changed its place in the ranking, as a consequence of the changed weighting, was the heat pump. It came in last for the project partner, mainly because of their focus on investment costs, and came in second for the environmentalist, mainly because of the large CO_2-saving potential. This means, that apart from the heat pump, the ranking is not largely dependent on the weights. However, a large part of the data collected consists of estimations, which means that the scores should be regarded with care.

The installation of public EV-charging stations is thus the best solution according to the MCA and is also the only one that generates a profit in itself. The Load management system has a high rank, however, it can be discussed if this is a useful solution if it is not financially profitable. For example, the practicality and safety can be considered irrelevant if the main goal of the solution, namely to make a system more profitable, is not reached. All the solutions including battery storage also turned out to be financially not viable. These might become more interesting if battery prices go down in the future. For now, only someone who values independence from the grid might want to make that purchase. Finally, the heat pump is not a good solution if the main goal is to make a PV-system more profitable. Especially in the case that was analysed, some retrofitting is necessary, in order to integrate the heat pump in an existing building, which leads to high investment costs. However, the potential of emissions saving is by far the highest for this solution, which makes it an interesting investment if the main goal is to reduce the greenhouse gas (GHG) emissions.

3 Limitations and recommendations for future research

When implementing the conclusions, some limitations should be taken into account. These limitations typically follow from scoping decisions, based on the time limitations for the project. In the first part of the report, where all the regulations, subsidies and financial constructions are mentioned, it should be noted that the data is based on the regulations and subsidies present at the time of writing this report (first two quarters of 2021). Due to changing conditions, these regulations and subsidies are subject to changes. When implementing this data, it should always be checked if the data is still applicable.

For part one of the report, presented in Appendix A, current technology is used. However, these technologies advance quickly, which means that when the results are used in the future, it should be taken into account that the mentioned technologies are already obsolete or improved. Also, specific cases are used to draw conclusions on, which means that it cannot be said that the conclusions are applicable on other cases. It would be an interesting future project to generalize the findings of this part of the report, and to verify whether the conclusions are generally applicable. Also, constant electricity prices are used, since it was out of scope to forecast the electricity price in the future. It would be interesting to perform a study with the aim to forecast electricity prices, or at least define different scenarios possible for the electricity price. Also, the conditions for different subsidies are not taken into account, the self-consumption parameter is a simplified representation of reality and the PV-system is not designed in full detail. These are potential improvements of the study that will improve the reliability.

The second part of the report is presented in Appendix B. This section aims to offer solutions to cope with the decrease of the net-metering scheme, and evaluates which option would be the best. The results are limited since it is based on one specific case. It would be interesting to see whether the conclusions are the same for other cases, and to see if the conclusions can be generalized. This would be an interesting topic for future research. Further, the input data are determined as detailed as possible, taking the time constraint into account. These input parameters surely can be researched more extensively, which will improve the viability of the results.Also, to assess data quality, a sensitivity analysis could be performed to conclude on which specific parameters are valuable to investigate in more detail. Especially the values for the self-consumption increase could be determined more accurately by performing a separate study. This is also an interesting future research direction. In addition to this, it is hard to choose one best option, since the definition of what is 'best' is subjective and highly depending on the interests of the person that defines the criteria.

Altogether, the report displays an extensive study on the installation of a PV-system on an apartment building and the operation of such a system without the net-metering scheme. The study is limited in time, which resulted in a lack of detail for some calculations and inputs. Further research on the aspects mentioned above is likely to improve the quality of the outcome.

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A Appendix: Current opportunities of PV-systems on apartment buildings

A.1 Literature research

In this first part of the report, the current opportunities of PV-systems on apartment buildings are discussed. This part is divided in three sections. The first section elaborates on the regulations for home owner's associations which relate to the installation of a PV-system on an apartment building. These rules are applicable for all the VvE's in the Netherlands, and are generally constituted. The second section discusses the subsidies and benefits that are applicable for the installation of a PV-system. The third section of this part discusses different forms of PV-systems that might be applicable for VvE's. For these systems, the technical, economic and legal feasibility are assessed.

A.1.1 Regulations for home owner's associations (Vereniging van Eigenaren)

In this section the general regulations of the VvE will be listed, which are relevant when installing a PV-systems on an apartment building. Each VvE can have different specific regulations, however the general regulations for every VvE are listed in a document called "Modelregelement bij splitsing in appartementsrechten" [4]. Since the specific rules for every VvE are not generally known and cannot be found anywhere, this document was used as a guidance to decide on which PV-systems are relevant for the VvE. The regulations in the document are categorized in different chapters, which will also be used for this paper. There are different subsections for each category, however, due to some overlap, multiple chapters in the document [4] are combined into one subsection in this report. The following categories, which are relevant for the installation of a PV-systems on an apartment building, will be discussed:

1. Communal property and sections
2. Costs, debts and responsibility for the VvE itself and its subdivisions
3. Establishment and adoption of the statutes of the VvE

These categories are relevant since they contain rules about changes to the building, financial rules and how rules can be changed to make sure that PV-systems are allowed.

Communal property and sections

1. The communal property and sections, which play a role in this project are: the sides of the building, the rough masonry, as well as the floors with the exception of the finishing layers in the private parts, the outer walls, the balcony constructions, the parapets, the terraces and the corridors, the roofs and the chimneys. Furthermore, it includes the technical installations with the associated pipes, especially for the central heating system (including the radiators and radiator valves in the private areas), the electricity cables, lightning protection and elevators.
2. A member of the VvE is not allowed to make changes in the shared parts or shared goods, when there is no permission of the members meeting, even if they are in private parts of the building.
3. Any construction, extension or substructure of the communal property without the permission of the meeting is prohibited. So when a member of the VvE wants to install a Plug-in PV-system on their balcony or terrace permission has to be asked.

Costs, debts and responsibility for the VvE itself and its subdivisions

1. Each member is obligated to contribute to the costs and debts of the communal property and sections. So when the VvE decides to install a PV-system each member should contribute to the costs and debts of the system.
2. In the event of subdivision, the rights and obligations of the owner of the apartment that is subject to the subdivision will be deemed to be the rights and obligations of the joint sub-owners in conformity with the provision laid down in the subdivision regulations. When the VvE gives permission to a group of members of the VvE to use the roof to install a PV-system, the group will form a subdivision.

3. If an apartment right belongs to more than one owner jointly, those owners will be jointly and severally liable for the obligations arising from that right, unless the community of property is a result of a subdivision.
4. The VvE will conduct the management over the communal sections and the communal property, and be responsible for the maintenance. So when the VvE decides to install a PV-system, the VvE will be responsible for the management and maintenance of the system.
5. In the event of a subdivision, the sub-owners will be jointly liable for complying with the obligations arising from the apartment right subject to the subdivision.
6. In the event of subdivision, the use, management and maintenance of the property subject to the subdivision will be provided for upon the subdivision with due observance of the provisions of the present regulations. So, if the VvE gives permission to a group of members of the VvE to use the roof to install a PV-system, the group will form a subdivision and be jointly liable and responsible for the management and maintenance of the system.
7. During the meeting of members, the decision can be made, to create a fund, which can be used to cover the costs related to reaching a specific goal. This fund can only be used for that specific purpose. So if the VvE decides to install a PV-system a fund can be raised to cover the related costs.

Establishment and adoption of the statutes of the VvE

1. A meeting must be held annually within the last six months of the financial year: the annual general meeting. Meetings will furthermore be conducted as often as the executive, the non-executive board or the chair believes necessary and as often as a number of owners (able to cast at least ten percent of the votes), requests the executive to do so in writing. This is important when members of the VvE want to discuss and vote about the possibilities to install a PV-system.
2. All resolutions must be accepted by an absolute majority of the votes cast, unless the present regulations or the law prescribe otherwise. For the present purposes, an absolute majority of the votes cast will be deemed to be: more than half of the votes cast in the meeting. For some important decisions, a VvE can state in their regulations that a higher quorum or a higher majority of votes is necessary, for example two-thirds of the votes. This is important for the voting to get permission to use the communal facilities for installing the PV-system.
3. The meeting of members can withdraw each permission, which was agreed upon in past meetings if there is an absolute majority of votes in favor of it.
4. In the case of subdivision, the voting rights accruing to the apartment right involved in the subdivision will be cast by the executive of the association of sub-owners in the ratio provided for upon the subdivision, in the sense that the ration between the voting rights accruing to the subdivided apartment rights and the other apartment rights may not be amended. This has to be taken into account when dividing the roof area among the participant that want to install a PV-system.

A.1.2 Current regulations, subsidies and financial aspects for the installation of PV-systems in the Netherlands

The aim of this section is to provide an overview of all the current regulations and financial incentives that might be applicable for the installation of a PV-system on apartment buildings owned by VvEs. At this moment there is no nationwide subsidy for PV-systems available in the Netherlands [5]. However, investments in PV-systems are stimulated via other subsidies, benefits and regulations. It is important to know all the subsidies and rules, since they can be used to finance the system partly and making the investment (more) profitable. Since these subsidies could have a big impact on the total cost of the system, it is important to include them in the assessment of different systems later in the report.

Tax back arrangement
Dutch private consumers can get the Value Added Tax (VAT) (Belasting Toegevoegde Waarde (BTW) in Dutch) refunded that was paid for the PV-system, including all materials used for the installation and the

installation itself [5]. The VAT on these payments is 21%, which means that it is possible to get back 21% of the investment [5]. This VAT refund is possible, because the Dutch tax authorities (Belastingdienst in Dutch) consider private individuals, who deliver electricity to the grid, as small businesses [6]. These small businesses can participate in an arrangement that is called the 'kleine ondernemersregeling' (KOR) in Dutch [6]. The KOR is only applicable when the revenue of the business is below €20,000. Furthermore, the VAT must be declared within six months after the end of the year in which the system was purchased [6]. VvEs are typically non-profit enterprises, which means that they are not tax liable. This means that such organisations do not have to pay tax on income, but also cannot get taxes back on purchases. When a VvE invests in PV-system to generate its own electricity, no tax back arrangement is available for the whole investment. During the first year it will be monitored which part of electricity generated by the system is used for their own consumption and which part is delivered back to the grid. Tax back can only be obtained for the percentage of the investment corresponding to the electricity delivered to the grid, since this is considered as delivering a service by the enterprise, so this part is tax liable. [7]

Local subsidies

As mentioned before, there has been no nationwide purchase subsidy for PV-systems since 2013. However, there are some subsidies that are offered by the province, region, municipality or water authority. Every organisation can decide on their own which subsidies they want to offer and under what conditions. [8]
In the municipality of Veldhoven, several subsidies and arrangements are available. One of the subsidies is an investment subsidy for sustainable energy for VvEs. Further, an energy savings loan for VvEs (VvE enegiebespaarlening in Dutch) exsists, as well as the stimulation loan (stimuleringsregeling in Dutch). At last, there is an option that provides extra mortgage for energy saving services. [9]

Investeringssubsidie Duurzame Energie (ISDE) voor VvE

VvEs can apply for a subsidy via the 'Investeringssubsidie Duurzame Energie'. This subsidy is applicable for solar boilers, heat pumps and central connections to the heat network. In addition to this, VvEs can apply for a subsidy for solar panels and small wind turbine as business users. To apply for this subsidy, the own electricity consumption must be at least 50,000 kWh, and the power of the solar system must be at least 15 kWp. The connection to the grid must be 3x80 Ampère or smaller to apply for this subsidy. The ISDE pays out €125 per kW peak capacity. [9] [10]

VvE Energiebespaarlening

The 'VvE Energiebespaarlening' is a loan that can be obtained by a VvE to finance energy saving measures such as insulation or a PV-system. This loan is characterised by a low interest rate (starting from 2.1%) to stimulate energy saving investments. To obtain this loan, the VvE must consist of at least eight residential units. The loan has a minimum of €25,000 in total, and a maximum of €25,000 per apartment, or a maximum total of €10,000,000. The loan has a low interest and a duration of 10, 15, 20 or 30 years. The interest is fixed for the whole duration. If the VvE wants to invest in multiple energy saving measures at the same time, there are some additional packages available: Zeer Energiezuinig Pakket (ZEP), Zeer Energie Zuinig Pakket + (ZEP+) or Nul op de Meter (NOM) packages. These packages have a maximum loan of €50,000 and €65,000 per apartment, respectively, and are only available if multiple investments are done at once. Only 75% of the loan can be used to finance solar panels, the other 25% must be used to finance other energy saving measures (such as facade insulation). [11], [12] [13]

Stimuleringslening

The municipality of Veldhoven also offers the 'SVn VvE stimuleringslening Duurzaam maken'. This is a loan with a relatively low interest rate. This loan can be used to invest in, for example, a PV-system or other sustainability measures. The minimum amount of money that has to be loaned is €15,000 and the maximum amount is €25,000, with a duration of 180 months. The interest rate is fixed for the duration of 180 months. [14]

Benefits for businesses

Business typically have different subsidies and benefits than cooperations and private users regarding PV-systems. This section elaborates on the different benefits and subsidies available for businesses.

Stimulering Duurzame Energieproductie (SDE++)

SDE++ is a subsidy that is not related to the purchase of a PV-system, but to the exploitation of such a system. This means that the subsidy is given out based on the amount of electricity produced. This subsidy is only available for businesses with a connection larger than 3x80 Ampère. In addition to this, the PV-system must be larger than 15 kWp. The application for this subsidy excludes a business from the Energie-Investeringsaftrek (EIA) subsidy, which will be discussed later. SDE++ can be applied for once every year, but there is no guarantee that this will be available every year in the future. When one applies for SDE++ subsidy, one can choose the applied subsidy them self with a maximum of €0.08 per kWh of electricity generated, however, only the projects that apply for the lowest amount of money per kWh, get the subsidy, and only a limited amount of money is available, which means that it is possible that some projects do not get any subsidy. [15] [16]

Milieu-Investeringsaftrek (MIA)

The Milieu-Investeringsaftrek (MIA) is a tax arrangement available for businesses, which yields tax benefits when investing in solar panels. With this arrangement, a company can deduct 36% of the investment costs of solar panels from their profit, which results in lower taxes payed on profit. This arrangement can be applied for in addition to the normal investment allowance (investeringsaftrek), so the company can benefit from both arrangements. [17]

Energie-Investeringsaftrek (EIA)

The EIA is another tax arrangement available for businesses. When the system complies with the requirements, 45% of the total investment cost (so including connection to the grid etc.) can be deducted from the fiscal profit of the company. There are two requirements that the system needs to fulfill: the system must have a combined peak power of at least 15 kWp and the connection must be equal or less than 3x80 Ampére. The maximum tax deductable cost is €750 per kWp. This arrangement cannot be used in combination with the SDE++. [18]

Kleinschalingheidsaftrek (KIA)

The KIA is another tax arrangement available for businesses. This arrangement can be combined with the EIA, which increases the benefits of investing in a PV-system. This arrangement may only be used when a company invests between €2,301 and €314,673 in one year in business assets. Business assets include for example office equipment or production equipment. When the PV-system is used to generate electricity for the business, this system is also a business asset. The investment in the system must be at least €450, and integrated solar panels are not included in this arrangement. The amount that can be deducted from the profit depends on the total investment. Until an investment of €55,000, 28% of the invested amount can be deducted from the fiscal profit. This percentage shrinks when the invested amount increases. [19]

Net metering scheme

Private users of PV-systems can profit from the net metering scheme (or salderingsregeling in Dutch) to increase the profitability of their system. When electricity, generated by the PV-system, is not used by the producer, it is delivered back to the grid. At such a moment, the producer also becomes an electricity supplier. Net metering means that the electricity delivered to the grid is subtracted from the energy consumed from the grid by the same party. This party only pays for the net electricity consumed at the end of the year (consumed electricity minus delivered electricity). However, when the amount of supplied electricity is larger than the amount of consumed electricity, the electricity retailer pays a reasonable feed-in tariff for this electricity. In the end, the energy bill can be significantly lower, or even negative, which increases the attractiveness of PV-system investments. The future of the net metering scheme is however uncertain. Current plans propose to decrease the benefits starting in 2023. The future of this arrangement will be analyzed in more detail in Chapter B.1.1. [20]

Postcoderoos and Subsidieregeling Coöperatieve Energieopwekking (SCE)

The Postcoderoos was an arrangement to subsidise cooperative sustainable energy projects. It ended in April 2021, which means is not applicable anymore. The Postcoderoos arrangement is replaced with a new arrangement: the Subsidieregeling Coöperatieve Energieopwekking (SCE). This arrangement provides a subsidy for local cooperative initiatives regarding the generation of sustainable energy, for example by PV-systems or wind turbines. The SCE started on the first of April 2021 and the target groups are energy cooperations and VvEs. The SCE is an exploitation subsidy, which means that the organization obtains the subsidy for every kWh produced in a certain period. The subsidy consists of a fixed sum per kWh

(0.146 €/kWh for small installations of 15-100 kWp and 0.121 €/kWh for large installations of 15-500 kWp) (webinar HierOpgewekt, 18-03-2021). In addition to this fixed amount, there is a correction amount, which is based on the yearly electricity price. The subsidy is granted for a period of 15 years as a yearly cash flow. For VvEs there needs to be at least one contributor per 5 kWp installed power. If not all members of the VvE agree to cooperate, a separate cooperation must be started. All the participants must be living in the 'postcoderoos' at the moment of application. A postcoderoos is an area in which people can participate in local energy projects. The postcoderoos is defined as the first four numbers of a zip-code (postcode in Dutch), with the neighboring zip-codes added to that. So when an individual lives in one of these zip-code areas, one can participate in energy projects issued in the central zip-code area [21]. There is no overlap allowed with the SDE++ subsidy and other local subsidies are subtracted from the SCE.

Loan from VvE
According to Ben Schreuder, who is part of the board of a VvE and member of the project partner Veldhoven Duurzaam, most VvEs have large cash reserves to cover for future costs, such as maintenance cost. At the moment of writing this report, the maximum interest rate on a savings account is around 0.3%, depending on which bank is chosen [22]. In addition to this, inflation in the Netherlands typically lies between 0.5% and 2.5% [23], which means that the actual value of funds stored in a savings account decreases and the VvE in fact loses money when it is stored in such a savings account. If the money were to be used as a loan to finance the PV project, returns can be made on the invested funds. This way, the project could have a relatively cheap financing, since no middlemen have to make profit on the loan, and the VvE creates an extra stream of income, which might result in a decrease of the monthly contribution for the residents.

Loan from the bank
To finance sustainable energy projects, a bank loan can be obtained. Multiple Dutch banks offer a green financing option for businesses (Groen Financiering in Dutch). Stef Bais, who is an accountmanager at ING bank provided useful information about their green financing options. This green financing has a minimum loan amount of €25,000 and a maximum loan amount of €35,000,000. The interest rate depends on the project (typically between 2% and 10% [24]), however, ING typically offers 0.5% interest discount on loans for sustainability projects. The duration of the loan is 20 years, and in every year 5% amortization. Mr. Bais also indicates that it is complex to provide financing to VvEs, since it is not always clear who is financed and who is responsible (VvE itself, or the individual participants of the VvE).

Which subsidies are available for the VvE are case dependent, based on the requirements of the subsidies. It is likely that SCE and SDE++ are applicable for VvE's, since they apply for larger projects, such as an apartment complex. Also, the net-metering scheme can be used when the individual apartments are connected to the PV-system. All types of financing can be used, however this remains case specific, based on which are most favorable..

A.1.3 Possibilities to organize the distribution of the costs, responsibilities and profits of a PV-system

Before applying the information about the regulations and subsidies regarding PV-systems for apartments, the types of systems that will be researched in this paper are described. The following categories are based on the end use and/or the type of system [25]. After describing some initial steps and giving an overview of the system types, the technological, legal, and economical feasibility will be discussed. The following system types will be considered:

1. Collective PV-system for communal utilities
2. Collective PV-system making use of SCE
3. Collective PV-system for participating owners
4. PV-system for individual use
5. PV-system for non-private use

Initial steps for all system types

The following actions and statutes are applicable for all the different implementations of PV-systems.

1. An assembly of the members of the VvE needs to be organised. An extraordinary assembly can be held, if a number of owners (able to cast at least ten percent of the votes), submit a written request to the executive. If no extraordinary assembly is possible, the members have to wait for the annual general assembly.
2. If the assembly gives permission to use the roof for installing a PV-system, the lifetime of the roofing material should be considered. Solar panels can have a lifetime of at least 25 years [26]. As most apartment buildings have flat roofs, the life time of these roofs depend on the roofing material used and the lifetime of the solar panels could be longer than the lifetime that is left on the roofing. For "normal" roof tiles this is less of a problem, because they can last up to 100 years [27]. In Table 3 the expected life time of different kinds of roofing is listed, here it can be seen that the expected lifetime of different roofing materials is typically longer than the expected lifetime of PV panels, which have an expected lifetime of 25 years. The VvE should consider replacing the roofing if the remaining life time of the roofing is less than the expected life time of the PV-system.
3. Note that in theory all the mentioned permissions could be withdrawn in a subsequent meeting of members if there are serious new objections and an absolute majority is in favor of this. However, this is unlikely to cause problems, because the members of the VvE will usually do not change rapidly.

Table 3: The expected life time of different roofing materials [27]

Roofing	**Expected life time [years]**
Bitumen	25-30
Rubber (EPDM)	40-50
PVC	25-35
TPO	30-40

Collective PV-system for communal utilities

The energy generated by the collective PV-system can be used to power communal facilities such as an elevator or the stairwell lighting. In this case, the residents' energy bills remain unaffected by the generated green energy. However, the member's contribution to the VvE may be reduced after the investment has been recouped.

Technical feasibility

A collective PV-system for communal utilities type is essentially technically feasible when the roof of the apartment complex is suitable for the necessary amount of solar panels. To test the general feasibility of this application, three examples of a small, medium and large apartment complex will be defined and simulated in the next phase of this study.

Legal feasibility

As explained in chapter A.1.1, the general steps to be taken in order to implement a PV-system on an apartment complex for this system type are:

1. An absolute majority of the votes (>50% of the votes) is required to be in favor for using the roof or side of the building to install a PV-system. Note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it. Furthermore, permission for using the communal fuse box is needed, to place the inverter and install the cables from the PV-system.
2. A fund has to be raised, which will be used to buy the PV-system, to carry out maintenance, to make an insurance contract and to cover other additional costs.
3. The responsibility of the PV-system lies with the VvE.

Economic feasibility

As explained in Chapter A.1.2, a VvE can benefit from different benefits and subsidies. Different types of financing a PV-system are possible: funds from a bank loan, funds from a VvE Energiebespaarlening and also a loan from the VvE's own reserves are part of the options. Since the aim of this system is to generate electricity (partly) for own use, this means that the VvE can apply for ISDE or SDE++ (these cannot be combined), but also use the net-metering scheme. These subsidies aim to stimulate the investment in sustainable energy generation, by increasing the profitability of such projects. Which type of funding and subsidy is used, depends on the type of system and organization that is chosen. Different subsidies have different conditions under which one can apply for it. These conditions typically consider the size of the projects and in which organization such a system is created (non profit association or a cooperation for example).

As mentioned previously, the economic profit for the members of the VvE is only reflected in the reduction of the VvE contribution. This contribution reflects the common expenses of a complex and is dependent on the size and type of the occupant's apartment related to the other apartments in the complex.

If more electricity is supplied back to the grid than is used on an annual basis, this surplus of supplied energy is not covered by the net metering scheme. The supplied energy is settled until consumption is zero. The surplus from the supplied energy is then sold through the energy supplier for a feed-in tariff [28]. For a model contract with an energy supplier (for an indefinite period, with variable rates) the feed-in tariff is currently between 3 and 12 cents per kWh [28]. Given that this fee can be considerably lower than the electricity price, it is financially more attractive to install a PV-system with an annual energy generation that is approximately equal to the communal utilities' annual energy consumption. The application is therefore economical feasible when the required roof area for the PV-panels is equal to or less than the usable roof area of the apartment complex.

In the next phase of this project, values will be set for the annual electricity consumption of the communal areas and the monthly VvE contribution for a small, medium and large apartment complex. Additionally, an estimate will be made of the investment and maintenance costs of the system. Based on these values, the above mentioned regulations and subsidies, and the technical simulation, the monthly savings of the VvE contribution is then calculated. Only then, a final conclusion can be made on whether this approach is feasible on technical, legal and economic grounds.

Collective PV-system making use of SCE

Another possibility is that the VvE as a whole or members of the VvE, who started a separate cooperation, install a collective PV-system, which will be "earned back" making use of the SCE subsidy. As already explained in Chapter A.1.2, the VvE or cooperation will obtain the subsidy for every kWh produced in a certain period. The subsidy consists of a fixed price per kWh. In addition to this fixed amount, there is a correction amount, which is based on the yearly electricity price.

Technical feasibility

A collective PV-system for communal utilities is essentially technically feasible when the roof of the apartment complex is suitable for the necessary amount of solar panels. To test the general feasibility of this application, three examples of a small, medium and large apartment complex will be defined and simulated in the next phase of this study.

Legal feasibility

As explained in Chapter A.1.1 and A.1.2, the general steps to be taken in order to implement a PV-system on an apartment complex for this system type are:

1. There needs to be a absolute majority of votes (>50%) in favor of using the roof or side of the building to install a PV-system. Note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it.
2. If not all members of the VvE agree to cooperate, a separate cooperation must be started. All the participants must be living in the 'postcoderoos' at the moment of application.
3. For VvEs there needs to be at least one contributor per 5 kWp installed power.
4. One can not combine the SCE subsidy with the SDE++ subsidy and other local subsidies are subtracted from the SCE.

5. A fund has to be raised, which will be used to buy the PV-system, to carry out maintenance, to make an insurance contract and to cover other additional costs.
6. The responsibility of the PV-system lies with the VvE or cooperation.

Economic feasibility
The SCE can be used when all the electricity is delivered to the grid, and when no electricity is used by the VvE itself. Section 2.2.5 elaborates the SCE. The SCE is an exploitation subsidy, which means that the VvE obtains a subsidy for every kWh produced by the PV-system. This subsidy consists of a fixed sum per kWh (0.146e/kWh for small installations of 15-100 kWp and 0.121e/kWh for large installations of 15-500kWp (webinar HierOpgewekt, 18-03-2021)).In addition to this fixed amount, there is a correction amount, which is based on the yearly electricity price. The subsidy is granted for a period of 15 years, as a yearly cash flow. This yearly cash flow can be seen as income for the VvE, and might result in a decrease of the VvE's members contribution.

Collective PV-system for participating owners
In this application, a PV-system is installed as a collaboration between some or all of the apartment owners. The generated solar energy is then distributed to the energy meters of the participating owners. The surplus of the generated solar energy is either returned to the grid according to the net metering scheme, or, for example, stored in a battery per participating apartment owner in order to increase the self-usage. This battery will then be connected at each apartment after the meter.

Technical feasibility
Due to the current state of development, the situation in which the surplus of the generated solar energy is returned to the grid according to the net metering scheme, and the generated solar energy is divided among the participating owners according to the ownership ratio is seen as the base case in this part of the research. In part two of this research, however, technologies to increase the self-use of the generated solar power is further elaborated upon.

In this case, the solar panels must be directly attached to the fuse box of the participating resident. This means a physical cable must go from the PV-panels to the residents' fuse box. Apart from this cable, an inverter has to be installed to convert the DC Voltage coming from the PV-system to AC Voltage, such that it can be connected to a group in the fuse box. The resident can install an inverter in their apartment, but this is not always possible as an inverter takes up space, generates heat, and sometimes makes noise [29]. Therefore, it is recommended to install the inverter of the pv-system in a separate space outside of the apartments.

It should also be taken into account that one area of PV-panels of the roof may yield less than the other. This, for example, due to shade from surrounding buildings or trees. Therefore, the roof division between participating owners with this system type must be taken into account.

To test the technical feasibility of this system, a simulation is again made of a small, medium and large apartment complex. However, given that the residents in this situation can decide for themselves whether they want solar panels and how many, there is no limitation for the maximum generation of the system. Additionally, the system can be purchased by the participating apartment owners, or even be rented from a third market party.

Legal feasibility
As explained in Chapter A.1.1, the general steps to be taken in order to implement a PV-system on an apartment complex for this system type are:

1. There needs to be a absolute majority of votes (>50%) in favor of dividing the area of the roof or side into parts to install the PV-systems of participants (to create the new sub division), note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it. Furthermore, permission is needed for using the communal fuse box, to place the inverter and install the cables from the PV-system, because the inverter will make too much noise in the fuse box of an apartment. Also permission is necessary for installing the splitters from the communal fuse box to the participating apartments.

2. After the subdivision is made the participants of the subdivision can raise a fund, with contribution according to the ownership ratio to cover the cost of the investment, maintenance and insurances.
3. The responsibility of the PV-system is for the sub-owners, furthermore they are jointly liable.
4. The voting rights of the new sub division will be cast by the executive of the association of sub-owners in the ratio provided for upon the subdivision, in the sense that the ratio between the voting rights accruing to the subdivided apartment rights and the other apartment rights may not be amended. The sub-owners should create rules and regulations about the costs, maintenance and voting procedure.

Economic feasibility
As explained in Chapter A.1.2, for such systems, ISDE and SDE++ can be applied, depending on which business model is used.

In contrast to the previous system type, the economic returns in this situation are directly settled with the energy bill of the participating resident of the apartment complex. In order to determine the economic feasibility of this system, assumptions will therefore be made in the next phase of this study for the average energy consumption and costs of an apartment in Veldhoven and therefore the associated savings. These saving will can then be compared with the stated initial investment or the renting price of the panels.

PV-system for individual use
In this application, a single resident purchases a PV-systems themselves, which has a direct connection to their own energy meter via the plug and play principle. The PV-system can be installed with permission from the VvE on the balcony or terrace of the owner's apartment.

Technical feasibility
Certain PV-systems are suitable to be placed on a balcony or terrace. In this case, the PV-system can be easily connected to the domestic power supply by plugging it into a regular wall socket [30], these panels are then referred to as plug and play solar panels. Since plug and play solar panels have their own build in inverter, they can be connected directly to the apartment's the fuse box. However, it is not possible to connect more than one set of solar panels with plug per group in the fuse box. This system is therefore technologically feasible if the resident in question has the option of placing the solar panel in a favorable location, such as on the balcony or on the terrace, and has a separate plug group available in the fuse box. The surplus of generated energy is then fed back to the grid according to the net metering scheme.

Legal feasibility
As explained in Chapter A.1.1, there needs to be a absolute majority of votes (>50%) in favor of using your balcony or terrace for placing a PV-system, note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it.

Economic feasibility
As explained in Chapter A.1.2, for such a system only the net-metering scheme can be used, since these are typically private connections without a business or cooperation created.

In order to determine the economic yield of such a system, the next phase of the research will be based on the technical specifications of an example system. This example system is the Supersola Advanced Plug and Play solar panel [31], of which the specifications are stated in Table 4.

Table 4: Specifications of the Supersola Advanced Plug and Play solar panel [31]

Capacity	300 Watt peak
Material	Black mono-crystalline
Estimated yield	264 kWh per year per panel in the Netherlands
Dimensions	1.73 by 1.08 by 0.125 meters (lxwxh)
Costs	€699 per panel

The Supersola system is modular, which means that the Supersola panels can be connected to each other. With more than 3 Supersola panels, however, they must be connected to a separate "empty" group (without other devices) in the fuse box. In addition, they must always be connected to an earthed socket [31]. In Figure 1 the Supersola Plug and Play solar panel is shown.

Figure 1: The Supersola Advanced Plug and Play solar panel [31]

The economic feasibility of this system will be researched on the basis of the above stated specifications of the Supersola Advanced Plug and Play solar panel, the stated regulations and subsidies and average energy costs of a apartment in the Netherlands.

PV-system for non-private use
In addition to directly using the proceeds of a PV-system, a VvE can also choose to rent out the roof to an organization that exploits solar panels. In this case, the generated electricity is not used directly by the VvE or apartment owners themselves.

Technical feasibility
This PV-system type is essentially technically feasible when the roof of the apartment complex is suitable for any amount of solar panels. However, many market parties set a minimum to the amount of square meters available for the exploitation.

Legal feasibility
As explained in Chapter A.1.1, there needs to be a absolute majority of votes (>50%) in favor of renting out the roof or side of the building to install PV-systems, note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it. Furthermore, there also needs to be permission for using the communal fuse box, to place the inverter and install the cables from the PV-system.

Economic feasibility
With this system type, the VvE or the participating residents of the apartment complex do not have to make an initial investment. Many parties that operate these systems work with a fixed fee per panel per year. The subsidies and other benefits typically flow to the company that operates the PV-system.

An example of such a company is Enie.nl. Enie.nl places solar panels and then pays a fixed annual rent payment to the roof's owner, which is on average € 3.50 per solar panel per year [32]. The company has set a minimum of 1200m2 of usable roof area to be able to build a profitable solar power installation.

Another example of such a company is Indi Energie, which rent roofs and then finances, realizes and operates the solar power system. Via a calculation tool on the company's website, the yields of the roof with a minimum roof surface of 1500 m^2 can be calculated [33]. According to this calculation tool, the minimum amount of roof surface can already yield € 195 per year for the VvE without a SDE +(+) subsidy application. With an SDE +(+) subsidy from 2018, this can amount to € 5,250 per year for the same roof.

This section presented all the technical, legal and economic information that is important when considering the different systems. This information will be used later in the report to compare the different systems and to determine which option is the best for the case that is presented later on.

A.2 Methodology

In order to determine which PV-system configuration is the most profitable, a financial model is designed, that assesses the different system types for different buildings. A road map in the form of a flow chart is then created, in which the results of the modelling are presented in a clear and easy way. The methodology related to the model and to the road map is described in this chapter.

A.2.1 Methodology of the simulation model

The simulation model is based on a cost benefit analysis. A CBA is used to evaluate the costs versus the benefits of a project. Specifically, a financial CBA is performed with the goal to determine if the PV-system is profitable. Another advantage of a CBA is that it can be used to compared different types of investment. The model is made using Microsoft Excel.

The basis of a CBA consists of the the yearly cash flows, which include the initial investment costs for the PV-system in year 0, revenues such as the cost reduction of directly used electricity, subsidies, cash flows from electricity sold to the grid, and yearly expenditures such as maintenance. To calculate the cash flows, first the destination of all generated electricity needs to be known. This is calculated in the electricity flow section.

Further, the cash flows need to be corrected, since the value of money decreases over time due to inflation. This is done by discounting the future cash flows, using the discount rate (r) (see equation 2). In this case, a combination of the inflation (i) and the interest rate (p) is used. The sum of all the discounted cash flows is the net present value (NPV), calculated as follows, with n being the index for the year and CF(n) being the cash flow of the year n:

$$NPV = \sum_{n=1}^{25} \frac{CF(n)}{(1+r)^n} \tag{1}$$

$$r = \frac{1+i}{1+p} - 1 \tag{2}$$

For a project to be profitable, the NPV needs to be a positive value. However, the NPV alone is not sufficient to evaluate the profitability of a project. The Internal Rate of Return (IRR) represents the relation between the total investment costs and the total profits. The IRR is the value of the discount rate for which the NPV is 0. For the PV-system to be profitable, the IRR needs to be higher than the discount rate. The IRR is calculated by setting the NPV in equation 1 equal to zero and solving for r.

Finally the Payback Period (PBP) is calculated. This value indicates the number of operating years after installing the system in which the total profits exceed the initial investment. This metric alone is not optimal for comparing investments, because it neglects cash flows after the break even point is reached. The combination of these financial indicators are helpful in making decisions regarding the investment in a project. Nevertheless, the results of the model are only useful for an initial exploration of available options. A more detailed calculation is needed to get a more reliable prediction. To gain more insight in the uncertainties caused by assumptions, a sensitivity analysis is performed, which can be seen in Section A.2.3.

Options available in the model
To fit the model to the specific cases, the user is allowed to select some options. Firstly, it's important to know what the PV-system is connected to. The options are: only connected to the communal facilities, only connected to households or connected to both. Furthermore, there are some investment subsidies that can be selected: the ISDE and the KOR. The available exploitation subsidies are: net-metering, SCE and SDE++. The model does not take the conditions of the subsidies into account, so this has to be done by the user.

Electricity flow
The purpose of the electricity flow section is to determine what the generated electricity is used for. First, a distinction is made between electricity generated for households and electricity generated for communal

facilities. This is necessary because these are separate grids. Then, the yearly generated electricity ($E_{gen,h/c}$) flows are corrected using the annual degradation percentage:

$$E_{gen,h/c} = E_{gen,h/c,n=1} * (1 - \%_{degen})^n \tag{3}$$

Then the amount of the generated electricity that is directly consumed is calculated by:

$$E_{self,h/c} = E_{gen,h/c} * SC_{h/c} \tag{4}$$

The amount of electricity eligible for net metering is equal to:

$$E_{nm} = (E_{gen,h} - E_{self,h}) * \%_{eligible\ nm}(year) \tag{5}$$

When more electricity is generated than consumed over one year, the excess of electricity is neglected.

Finally, the electricity fed to the grid is determined by:

$$E_{feed} = E_{gen} - E_{self} - E_{nm} \tag{6}$$

Cash flow
The cash flow is the net amount of money the VvE spends and receives regarding the PV-system every year. It consists of one-off and yearly expenditures and revenues.

Expenditures
The expenditures include the initial investment, taxes on this investment and yearly maintenance costs. When the KOR is used, first the self-consumption during the first year is measured. Then the VvE can receive tax back from the initial investment corresponding to the percentage that is fed into the grid.

Revenues
The first revenue is the electricity that doesn't have to be bought from the grid as a consequence of the installation of the PV-system, called direct electricity cost reduction:

$$C_{reduction} = E_{self} * (\text{Electricity tariff} + \text{taxes} + \text{ODE}) \tag{7}$$

The profits received from the net metering scheme are equal to:

$$C_{nm} = E_{nm} * (\text{Electricity tariff} + \text{taxes} + \text{ODE}) \tag{8}$$

The profits received from feeding electricity to the grid are determined using the following equation:

$$C_{feed} = E_{feed} * (\text{Feed-in tariff}) \tag{9}$$

The SCE-contribution is calculated using the following equation:

$$C_{SCE} = E_{self} * (\text{Base amount} - \text{Correction amount}_{self}) + E_{feed} * (\text{Base amount} - \text{Correction amount}_{feed}) \tag{10}$$

When the generated electricity exceeds the predetermined maximum generated electricity set by the government, this maximum value is used to determine the E_{self} and E_{feed}.

The SDE++ contribution is calculated in an identical manner to SCE, but with different values base and correction values.

Input parameters
Considering the scope of the project, some assumptions are made to simplify the model.

Building specifications
To calculate the electricity flow, the amount of participating households in the project and their average

yearly electricity consumption in kWh is needed as well as the average yearly electricity consumption of the communal facilities. The self-consumption is a parameter dependent on lots of factors and too complex to directly calculate using the yearly data. So, instead the self-consumption is determined based on data from 144 households in Ulm, Germany [34]. In this data a correlation between the ratio of the PV system size and yearly consumption is found, see Table 5. This is used to set up a linear formula.

$$SC_{h/c} = -0.6 * \frac{E_{gen,h/c}}{E_{con,h/c}} + 0.96 \tag{11}$$

In reality the self-consumption is a very complex parameter dependent on weather and consumption patterns. Simulating these lays beyond the scope of this project.

Table 5: Self-consumption for different system sizes.

PV system size ratio	Self-consumption(%)
1/3	76.3
1/2	59.4
1	36.0

PV-system specifications

The design of the PV-system is not done within the model. The user has to request an offer from a contractor, to get the necessary specifications or the user should make estimations regarding the PV-system design. These specifications are used as an input for the model. The amount of panels, the nominal power in watt-peak [W_p], the amount of generated electricity per year [kWh] and the total installation costs excluding taxes are needed. The efficiency of the PV-panels degrades over time. It is assumed the efficiency reduces to 85% in 25 years. This gives a yearly degradation if 0.5 [%/year] [35].

To get an insight into the costs of installing a PV-system on an apartment building for the model, an offer was requested to Rob Verkuijlen from 365zon.nl for two cases at the VvE of which Ben Schreuder from Veldhoven Duurzaam is a board member(Zandbloem Veldhoven). The first case was for implementing the PV-system for communal use and the other case for wiring cables to each apartment. The design of the PV-system was done with five solar panels per apartment. The results of the design can be seen in Figure 2. For the case where the solar panels are wired to each apartment, a design was made where the solar panels are grouped per inverter, as can be seen in Figure 3. The important data from the offer of Rob Verkuijlen can be seen in Table 6, such as costs and specifications of the PV-system.

Figure 2: The solar panels placed on the roof of one of the five buildings of the VvE Zandbloem

Figure 3: The solar panels grouped per inverter for each apartment

Table 6: PV-system specifications for one of the five buildings of the VvE Zandbloem

Specification	**Value**	**Unit**
Peak Power	360	Wp
Cost installing Communal case (ex BTW)	25715	Euro
Cost installing individual case (ex BTW)	36370	Euro
Solar panels per apartment	5	modules
Total amount of solar panels	85	modules
Total amount of generated electricity per year	28135	kWh

Furthermore, when installing the PV-system the following practical actions have to be taken for both implementation cases: A ventilation grate has to be made in each fuse box, because the inverters need to get rid of the produced heat. Furthermore the fuse boxes need to meet the NEN1010 requirements, per four groups a residual current device and a main switch. Lastly some roof ducts have to be made, such that the cables from the solar panels can be connected to the fuse box and inverter. The difference between the communal and individual case is caused by the cabling of the five solar panels to each apartment, also the inverter and ventilation costs are higher.

Due to the time limit of the project, only an offer of VvE Zandbloem was made. The cost and performance of the PV-systems for the other VvEs were based on this case, by calculating the amount of solar panels per m^2, the cost per solar panel and the performance per solar panel. This way these parameters are estimated for the other VvEs.

Maintenance costs

PV-panels are a low maintenance technology and any technological errors in the panels are covered by the warranty for the entire scope of the project. However, the panels need to be cleaned regularly to prevent a reduction in efficiency. The costs and frequency of cleaning panels are very case specific depending on the amount of panels, type of roof and available space. It is recommended to request offer for cleaning the PV-system from a cleaning service.

A.2.2 Assumptions for apartment complexes and system categories

As described in the chapter A.1.3, a subdivision was made of five system categories based on the end use and/or the type of system. These five system categories are simulated for multiple apartment complex sizes. In these simulations, several quantitative assumptions were made.

Assumptions for apartment complex sizes

In order to simulate the defined five different system categories, six reference cases were gathered. These reference cases were partially supplied by Veldhoven Duurzaam (case 1), but mostly provided in collaboration with Compagnon Vastgoedbeheer (case 2-6), who manage VvEs for several apartment complexes in and around Veldhoven. The different cases were simulated, to analyse if the outcome is dependent on the apartment complex size. In Table 7, the quantitative assumptions used as input for the calculations are illustrated.

Table 7: The defined six apartment complex cases to be simulated

Case reference	**Zandbloem**	**Blauwven**	**Oortlaan**	**Don Bosco-straat Zuid**	**Den Hoorn**	**Reijenburg, Holsteiner**
No. of apartments	87	6	24	22	60	21
Roof surface [m2]	2.400	300	835	574	580	520
Elec. use of communal facilities [kWh/y]	80.000	13.660	4.700	35.000	82.500	10.000
Type of grid connection of communal section	3x160A	3x35A	3x25A	3x50A	3x63A	3x35A
Average VvE contribution [€/m]	€182	€250,00	€81,00	€127,00	€136,00	€149,00

As a general assumption, it is assumed that the average annual electricity consumption of an apartment is equal to the average annual electricity consumption of a Dutch household, namely 2500 kWh [36].

Assumptions for system categories

Apart from the quantitative assumptions for the six apartment complex sizes, several other quantitative assumptions were made for the system categories in order to conduct the simulations. Five system categories were defined, for which the assumptions are presented below.

Collective PV-system for communal utilities making use of SCE or SDE++

For this implementation, the VvE will make use of the SCE or SDE++ subsidy. The amount of solar panels that can be placed on the roof for this implementation is based on the electricity use of the communal facilities of the VvE, such that the electricity generated by the solar panels equals the consumption of the communal facilities. This means that in some cases, not the full roof was filled.

Collective PV-system for participating owners
In this case the whole roof will be filled with solar panels and the total generated electricity is divided among the apartments in the VvE. The assumption was made that all the apartments owners wanted to participate.

Combination of a Collective PV-system for communal utilities making use of SCE and participating owners
When the roof was not totally filled with solar panels in the case of a collective PV-system for communal utilities making use of the SCE subsidy, the space left was used to install solar panels which were connected to some apartments as in the collective PV-system for participating owners implementation. To avoid additional costs of connecting the solar panels to apartments, the amount of apartments that will be connected is calculated such that the generated electricity of the extra installed PV-system is equal to the consumption of the connected apartments. The obtained revenue from the PV-system connected to the apartments should be divided among all members of the VvE, however this is a practical issue as in the model only the total combined result will be discussed. This combination calculation was not done for SDE++, because the revenue obtained by this subsidy is lower than the SCE.

PV-system for individual use
For modelling a Plug-in system, the calculation was done for one Supersola Advanced Plug and Play solar panel 1, of which the specifications can be found in Table 4. To make the calculation flexible and scalable, the calculation was done for just one panel, because the amount of solar panels that can be placed is very case specific.

PV-system for non-private use
For the option of renting out the roof to an energy company, the earlier explained proposal of Enie.nl was used, the first 16 years, the VvE receives €3.50 per solar panel. After this period the VvE takes over the PV-system for free and the PV-system generates electricity, which can be consumed or fed into the grid. Only the VvE Zandbloem of the six reference cases can apply for this implementation, because the roof area should be at least $2000m^2$.

A.2.3 Methodology of sensitivity analysis

To gain better insight into the effects of uncertainties of assumed values a sensitivity analysis is performed. The input values examined are the initial year of operation, the self-consumption, and the correction amounts of the SCE. The output values tested are the NPV and IRR. The case of the complex Zandbloem is used, because here the data regarding the PV-system is most detailed. The values are only examined in the category where they are most relevant.

The sensitivity is quantified as the effect of a change in input on the output. For example, when the sensitivity is 0.25 this means a change of 1% in the input results in a 0.25% change in the output. The average of a range of different inputs is taken.

$$Sensitivity = \frac{1}{\text{Amount of inputs}} \sum \frac{\text{\% change in output}}{\text{\% change in input}} \tag{12}$$

Due to the nature of data tables in Microsoft Excel, in cases where the input consists of two variables, like the correction amounts of the SCE, only one output is investigated. The sensitivity is calculated only when the two input variables both change the same amount.

A.2.4 Visualization of the simulation results in a Road Map

As described in the methodology introduction, a road map in the form of a flow chart is created for the steps to be taken by a VvE or individual, when choosing a PV-system category. In order to best highlight the most feasible PV-system categories, the simulation results of the five system categories are used for drawing up the flowchart.

The online diagram software Lucid Chart is used to create the flow chart. The to be followed flows in the road map are drawn up by comparing several example formats. These example formats are weighed against another in order to come to the best alternative. In addition to these category flows, an explanation will also be given per system category, so that the user can use this flow chart separately from this report.

A.3 Results

To answer the first research question of this study: *What are the threats and opportunities regarding economics, technicalities and regulations concerning photovoltaic systems for apartment buildings?*, a model has been set up containing five different PV-system categories. These five different PV-system categories were then processed in a road map in the form of a flow chart as a way to visualize the results.

A.3.1 Results of the simulation model

Collective PV-system for communal utilities making use of SCE or SDE++

The results of the model for communal utilities making use of SCE can be seen in Table 8 and the results for the SDE++ subsidy in Table 9. As can be seen in Table 8, the average IRR and PBP for the SCE are respectively 18% and 6 years. As can be seen in Table 9, the average IRR and PBP for the SCE are respectively 13% and 9 years. As a result a VvE can preferably apply for a SCE subsidy. In both results the VvEs Don Boscostraat Zuid and Den Hoorn score differently in comparison with the other VvEs, because on these apartment buildings there was not enough space left to cover the electricity consumption of the communal facilities, this way the ratio of the generated and consumed electricity is lower and the self-consumption percentage will be higher, see Eq. 11. This will result in higher IRR and lower PBB, however the NPV will be lower.

Table 8: The results of the model for communal utilities making use of SCE starting in 2021 for 25 years

VvE	**NPV** [€]	**IRR** [%]	**PBP** [y]
Zandbloem	218889	17	6
Blauwven	40178	18	6
Oortlaan	12450	18	6
Don Boscostraat Zuid	98261	21	5
Den Hoorn	131553	26	4
Reijenburg, Holsteiner	28763	18	6

Table 9: The results of the model for communal utilities making use of SDE++ starting in 2021 for 25 years

VvE	**NPV** [€]	**IRR** [%]	**PBP** [y]
Zandbloem	158718	13	9
Blauwven	24846	11	9
Oortlaan	7563	11	10
Don Boscostraat Zuid	69450	15	7
Den Hoorn	103949	20	6
Reijenburg, Holsteiner	18106	12	9

Collective PV-system for participating owners starting in 2021 for 25 years

The results of the model for a collective PV-system for participating owners can be seen in Table 10. As can be seen in Table 10, the average IRR and PBP for the participating owners are respectively 15% and 7 years. The IRR result of the VvE Blauwven is a bit different in comparison with the other VvEs, because the self-consumption percentage is lower.

Table 10: The results of the model for a collective PV-system for participating owners starting in 2021 for 25 years

VvE	**NPV** [€]	**IRR** [%]	**PBP** [y]
Zandbloem	372781	15	7
Blauwven	32744	13	7
Oortlaan	117630	15	7
Don Boscostraat Zuid	89467	15	7
Den Hoorn	106727	16	7
Reijenburg, Holsteiner	81861	15	7

Combination of a Collective PV-system for communal utilities making use of SCE and a Collective PV-system for participating owners

The results of the model for a combination of a collective PV-system for communal utilities making use of SCE and participating owners can be seen in Table 11. As can be seen in Table 11, the average IRR and PBP for the participating owners are respectively 16% and 7 years. Only three VvEs can implement this system, because the other buildings did not have space left after covering the electricity for the communal facilities.

Table 11: The results of the model for a combination of a Collective PV-system for communal utilities making use of SCE and a Collective PV-system for participating owners starting in 2021 for 25 years

VvE	**NPV** [€]	**IRR** [%]	**PBP** [y]
Zandbloem	317143	16	7
Blauwven	-	-	-
Oortlaan	114097	15	7
Don Boscostraat Zuid	-	-	-
Den Hoorn	-	-	-
Reijenburg, Holsteiner	700361	16	7

Pv-system for individual use starting in 2021 for 25 years

For the PV-system of individual use, a singe panel is considered. This panel can generate a NPV of €710, an IRR of 10% an a PBP of 10 years.

PV-system for non-private use starting in 2021 for 25 years

The total revenue of renting out the roof of the VvE Zandbloem placed in Veldhoven is €174769.This corresponds to a NPV of €118495. The PBP and IRR can not be calculated for this example, because no initial investment is made.

Comparison different system implementations The PV-system for individual use and the PV-system for non-private use are more difficult to compare to the first 4 options. The PV-system for individual use looks at only one panel, so the NPV can not be compared to the other cases. However, the PBP is higher and the IRR lower, that for the other cases, so it can be concluded that this system is less favourable. For the PV-system for non-private use, no IRR and PBP could be calculated, so only the NPV can be compared, which is lower than for the other cases. One could conclude thus, that it is less favourable, but it is important to keep in mind, that no investment is needed, which could make this option attractive in some cases.

The comparison of the other implementations can be seen in Table **??**, where a rank between one and four was given to the different system implementations for the NPV, IRR and PBP. As can be seen, for the IRR and PBP the SCE subsidy option is the best, the NPV is the best for the participating owners option, however due to higher investment costs the IRR and PBP are third best, which make the option less favorable. Furthermore, the performance of the participating owners implementation will reduce, when starting the project at a later year due to the potential phasing out of the net-metering scheme. This will be discussed in the sensitivity analysis about the initial year of operation. Therefore, the collective system, which makes use of the SCE is favorable, however when there is still space left to install extra solar panels, one can prefer to have a higher NPV against a lower IRR and higher PBP, then one should opt for the combination of a PV-system for SCE and participating owners.

Table 12: The ranking of the NPV, IRR and PBP of the different implementations, where the best is placed first and the worse implementation is placed sixth.

\textbf{Implementation}	**NPV [Rank]**	**IRR [Rank]**	**PBP [Rank]**	**Overall [Rank]**
SCE	3	1	1	1
SDE++	4	4	4	4
Participating owners	1	3	3	3
Combi SCE and participating owners	2	2	2	2
Non-private use	5	-	-	5
Individual use	-	6	6	6

A.3.2 Sensitivity analysis

Initial year of operation

The net metering scheme will be phased-out from 2023 to 2031. This makes the initial year of operation important for the total profitability of the PV-system.

The category that is most dependent on net-metering is the Participating owners. The changes in NPV, IRR and PBP are calculated, see Table 13.

Table 13: Sensitivity on initial year of operation

Initial year	**NPV**	**IRR**	**PBP**
2021	€ 363,162.96	14.91%	7
2022	€ 353,940.36	14.52%	7
2023	€ 344,489.67	14.08%	7
2024	€ 335,782.02	13.66%	8
2025	€ 327,835.80	13.26%	8
2026	€ 320,669.83	12.89%	8
2027	€ 314,303.41	12.55%	8
2028	€ 308,756.32	12.25%	9
2029	€ 304,048.82	11.98%	9
2030	€ 300,201.67	11.76%	9
2031	€ 297,236.15	11.57%	9

Even though the system will stay profitable, the initial year of operation is very important for the profitability of the project. With every year the project is delayed, the project owner misses out on about €10,000 of subsidy. On average every year the NPV reduces with 1.82%.

Self-consumption

In reality, the self-consumption is dependent on the weather, the consumption patterns and the system size. In the model this is highly simplified to only be dependent on the ratio between the generated and consumed electricity. The effects on the output when the value is wrong by -20%, -10%, -5%, 5%, 10% and 20% are calculated.

The categories Communal SCE and Combination SCE are investigated, because they are the most profitable. For the latter, a distinction is made between self-consumption by the households and the communal facilities. Because two variables are investigated only the NPV is calculated.

Table 14: Sensitivity on self-consumption for Communal SCE

Self-consumption	**NPV**	**IRR**	**PBP**
0.36	€ 188,160.68	13.35%	8
0.288	€ 162,897.35	12.12%	8
0.324	€ 175,509.69	12.74%	8
0.342	€ 181,815.86	13.05%	8
0.378	€ 194,428.21	13.65%	8
0.396	€ 200,734.38	13.95%	8
0.432	€ 213,346.72	14.54%	7

The self-consumption has a moderate effect on the profitability of the PV-system. A change of 5% results in a difference of €7,000 in the total profitability of the system. A large change in the self-consumption of 20% results in the IRR changing with just 1.2%. The sensitivity of the NPV and IRR are 0.67 and 0.45 respectively.

Table 15: Sensitivity of NPV on self-consumption of Combination SCE and net metering

House. Comm.	0.312	0.351	0.3705	0.4095	0.429	0.468
0.288	€ 274,775.12	€ 278,529.65	€ 280,406.91	€ 284,161.44	€ 286,038.70	€ 289,793.23
0.324	€ 287,387.46	€ 291,141.99	€ 293,019.26	€ 296,773.78	€ 298,651.05	€ 302,405.58
0.342	€ 293,693.64	€ 297,448.16	€ 299,325.43	€ 303,079.96	€ 304,957.22	€ 308,711.75
0.378	€ 306,305.98	€ 310,060.51	€ 311,937.77	€ 315,692.30	€ 317,569.57	€ 321,324.09
0.396	€ 312,612.15	€ 316,366.68	€ 318,243.94	€ 321,998.47	€ 323,875.74	€ 327,630.27
0.432	€ 325,224.50	€ 328,979.02	€ 330,856.29	€ 334,610.82	€ 336,488.08	€ 340,242.61

The initial value of the NPV is €307,524.85 for a household and communal self-consumption of 0.39 and 0.36 respectively. The change in output is similar to the Communal SCE category. A change of 5% of the inputs corresponds to a change in the output of €8,000. A 20% change results in a difference of €30,000. The sensitivity of the NPV on the self-consumption is 0.53.

SCE correction amounts

The correction amount for feed-in and self-use are used to calculate the SCE-contribution. The government will change this amount yearly, which is why it is useful to analyse their influence on the output. Changes of the input by -15%, -10%, -5%, -5%, 10% and 15% are taken into account.

Again the categories Communal SCE and Combination SCE are investigated. The initial conditions are a SCE correction amount for feed-in and self-use of 0.034 and 0.071 €/kWh respectively. This results in a NPV of €188,160.68.

Table 16: Sensitivity of NPV on correction amounts for feed-in and self-use for Communal SCE

feed-in Self-use	0.0289	0.0306	0.0323	0.0357	0.0374	0.0391
0.0604	€ 195,103.79	€ 194,039.81	€ 192,975.83	€ 190,847.86	€ 189,783.87	€ 188,719.89
0.0639	€ 193,853.40	€ 192,789.42	€ 191,725.44	€ 189,597.47	€ 188,533.48	€ 187,469.50
0.0675	€ 192,603.02	€ 191,539.03	€ 190,475.05	€ 188,347.08	€ 187,283.10	€ 186,219.11
0.0746	€ 190,102.24	€ 189,038.26	€ 187,974.27	€ 185,846.30	€ 184,782.32	€ 183,718.34
0.0781	€ 188,851.85	€ 187,787.87	€ 186,723.88	€ 184,595.92	€ 183,531.93	€ 182,467.95
0.0817	€ 187,601.46	€ 186,537.48	€ 185,473.49	€ 183,345.53	€ 182,281.54	€ 181,217.56

The sensitivity on the SCE correction is relatively small, with a value of -0.25. This means a change of 1% in the output corresponds to a reduction in the NPV of 0.25%.

The Combination SCE category is less sensitive than the Communal version, the sensitivity is -0.17.

Table 17: Sensitivity of NPV on correction amounts for feed-in and self-use for Combination SCE

Self-use \ feed-in	0.0289	0.0306	0.0323	0.0357	0.0374	0.0391
0.0604	€ 315,160.19	€ 313,865.47	€ 312,570.74	€ 309,981.30	€ 308,686.57	€ 307,391.85
0.0639	€ 313,909.80	€ 312,615.08	€ 311,320.35	€ 308,730.91	€ 307,436.18	€ 306,141.46
0.0675	€ 312,659.41	€ 311,364.69	€ 310,069.97	€ 307,480.52	€ 306,185.79	€ 304,891.07
0.0746	€ 310,158.64	€ 308,863.91	€ 307,569.19	€ 304,979.74	€ 303,685.02	€ 302,390.29
0.0781	€ 308,908.25	€ 307,613.52	€ 306,318.80	€ 303,729.35	€ 302,434.63	€ 301,139.91
0.0817	€ 307,657.86	€ 306,363.14	€ 305,068.41	€ 302,478.96	€ 301,184.24	€ 299,889.50

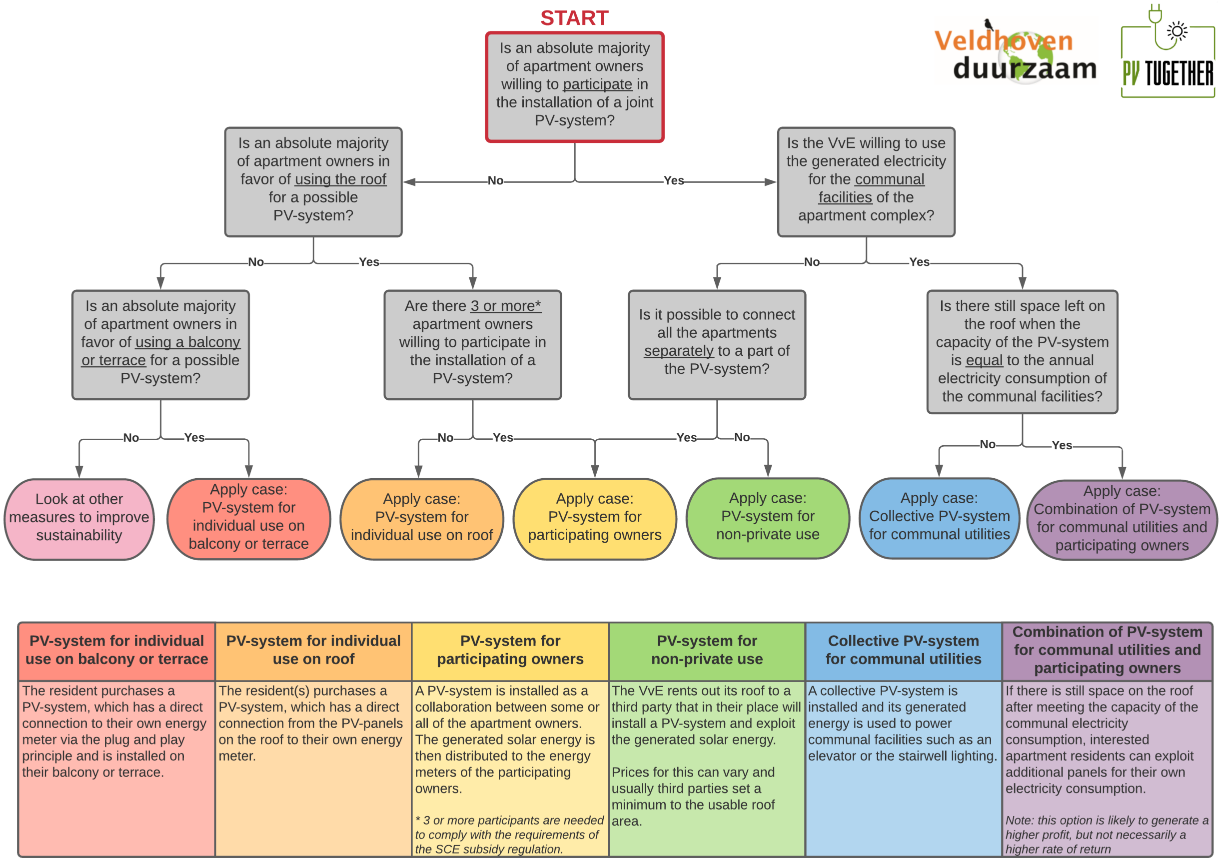
When net metering is used the initial year of operation is significant to the profitability of the PV-system. The self-consumption has moderate effect on the commercial viability of the project. And the correction amounts of the SCE have little effect on the NPV.

Table 18: Sensitivities on input values

Input	**Category**	**Sensitivity of NPV**
Initial year of operation	Participating owners	1.82
Self-consumption	Communal SCE	0.67
	Combination SCE	0.53
Correction amouts SCE	Communal SCE	-0.25
	Combination SCE	-0.17

A.3.3 Results of the road map

The above results of the simulation model have been incorporated in the flows within the road map. In Figure 4, the first page of the road map is presented. In Appendix D: Road Map, the road map is shown in full size with the corresponding second page with additional information.



PV-system for individual use on balcony or terrace	PV-system for individual use on roof	PV-system for participating owners	PV-system for non-private use	Collective PV-system for communal utilities	Combination of PV-system for communal utilities and participating owners
The resident purchases a PV-system, which has a direct connection to their own energy meter via the plug and play principle and is installed on their balcony or terrace.	The resident(s) purchases a PV-system, which has a direct connection from the PV-panels on the roof to their own energy meter.	A PV-system is installed as a collaboration between some or all of the apartment owners. The generated solar energy is then distributed to the energy meters of the participating owners. ** 3 or more participants are needed to comply with the requirements of the SCE subsidy regulation.*	The VvE rents out its roof to a third party that in their place will install a PV-system and exploit the generated solar energy. Prices for this can vary and usually third parties set a minimum to the usable roof area.	A collective PV-system is installed and its generated energy is used to power communal facilities such as an elevator or the stairwell lighting.	If there is still space on the roof after meeting the capacity of the communal electricity consumption, interested apartment residents can exploit additional panels for their own electricity consumption. *Note: this option is likely to generate a higher profit, but not necessarily a higher rate of return*

Figure 4: Road map front page

B Appendix: Increasing self-consumption of electricity produced by a PV-system

B.1 Literature research

In a future scenario, without the net metering scheme or a favorable feed-in tariff for electricity, it becomes financially interesting for prosumers to use as much of the electricity produced by a PV-system directly on-site as possible, instead of feeding it into the grid. In other words, the self-consumption of energy should be as high as possible. One could imagine for example a scenario, where you would get 10ct for electricity that you feed into the grid, but you would have to buy it back for 22ct.

Self-consumption is defined as the amount of power directly used within the building in relation to the total amount of produced power. In Figure 5 the area C represents the power consumed directly on-site, and the area $B + C$ represents the total amount of produced power. The self-consumption can thus be expressed as follows [37]:

$$self\text{-}consumption = \frac{C}{B + C}$$

In contrast, another metric that is often used is the self-sufficiency. This parameter indicates how much of the total consumed energy is produced on-site. In reference to Figure 5 the self-sufficiency can be expressed as follows [37]:

$$self\text{-}sufficiency = \frac{C}{A + C}$$

There are essentially two principles that can increase the self-consumption of electricity, which are energy storage and active load shifting. The idea of energy storage is to store the surplus of electricity that is produced, especially in the middle of the day, and use it at a later time, where the produced electricity doesn't cover the loads, or there is no production at all. Load shifting, on the other hand, considers the consumption, instead of looking at the supply. The idea is to move loads in time, so that their consumption matches the production by the PV-system. Both principles are also illustrated in Figure 5 [37].

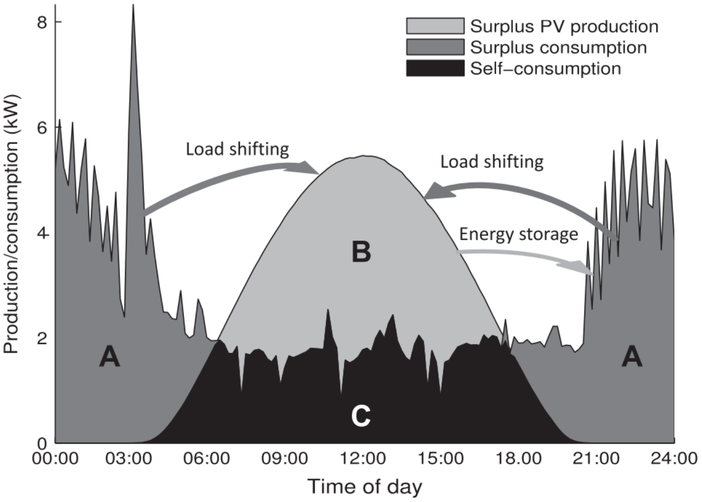


Figure 5: Schematic outline of daily net load (A + C), net generation (B + C) and absolute self-consumption (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing the self-consumption. [37]

In the following parts, the future of the net metering scheme in the Netherlands will be discussed, so that readers get an idea how it might evolve in the future. Subsequently, an overview of different technical solutions, that allow an increasing self-consumption, will be presented. First, the possibilities of energy storage solutions will be explored, then load shifting solutions will be presented.

B.1.1 Future of the net-metering scheme

Net metering has been the primary tool of the government to heavily stimulate the implementation of local electricity generation. However, the Dutch government has proposed a bill to slowly phase out the net metering scheme. From January 1st 2023 on the amount of electricity delivered to the grid, that can be subtracted from the energy bill, will be reduced by 9% every year. One reason for this is, that PV-panels prices are dropping steadily and thus are less reliant on subsidies. Moreover, after an evaluation of the effects of the net metering scheme the government concluded net metering is a relatively expensive emission reduction measure, with a value of €269 per ton of CO_2-eq circumvented [38]. Thus it was decided to rearrange the funds available for subsidies. Furthermore, when too many citizens use the net metering scheme, a surplus of energy on sunny days causes net-congestion, resulting in negative electricity prices. This had already happened in Germany. To solve this problem, Germany has abolished their net metering scheme in exchange for a feed-in subsidy. This tariff is fixed at the year of purchase and given for 20 years. Every subsequent year this tariff reduces for new installations. This situation can be used as input to estimate scenarios that might occur in the Netherlands in the future when the net-metering scheme might be abolished.

The current demissionary cabinet has decided to leave the decision on this bill to the next government. Considering the last formation of a government took 225 days and net metering has been a point of discussion since 2018, a lot of uncertainty surrounds the subject, making it hard to make clear predictions. There are rumors regarding a feed-in subsidy, but nothing official has been published. This all results in a lot of projects not getting of the ground. This indicates how uncertain the future of the net-metering scheme is, and that it is hard to make predictions for it.

Assuming that the bill mentioned above will go into practice, a cost benefit analysis has been conducted, in order to gain insight on what this would entail. Based on the yearly amount of electricity consumed and generated by a prosumer, the NPV, the IRR and PBP are calculated for projects starting a different times. First, the initial costs of the project are calculated based on yearly expected amount generated electricity. The installed capacity is calculated based on a yield of 0.9 [kWh/Wp] [39]. Then the costs can be calculated based on development costs of 2 [€/Wp] [40]. Then based on the self-consumption [34], electricity and feed-in tariffs, taxes and network operation costs the yearly cash flows are calculated.

The NPV and IRR are calculated using an inflation rate and market interest rate of 1.1% and 4% respectively. To keep things simple some assumptions have been made. The PV-panels have a life span of 25 years, they do not reduce in efficiency and require no maintenance. In addition, the PV-panel prices and electricity prices are kept constant over the next 10 years.

For the first case, a cost benefit analysis has been made for a consumption and generation of 3500 and 2500 kWh respectively, which corresponds in general to a self-consumption of around 0.3. For the second case more electricity is generated than consumed, 3500 kWh is consumed and 4500 kWh is generated. This increase in consumption and generation results in a lower self-consumption of about 0.2. Finally, a case where much less energy is generated than consumed, 1200 kWh is generated and 3500 kWh is consumed. For this case, a high self-consumption of 0.7 is assumed. The values for the self-consumption in all three cases are assumed to be reached without any measures to specifically increase self-consumption, such as storage or load shifting.

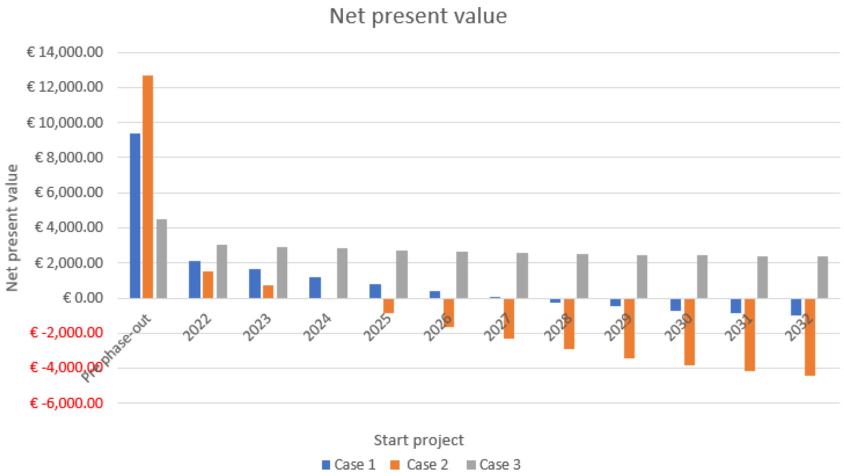


Figure 6: NPV of projects for different starting year

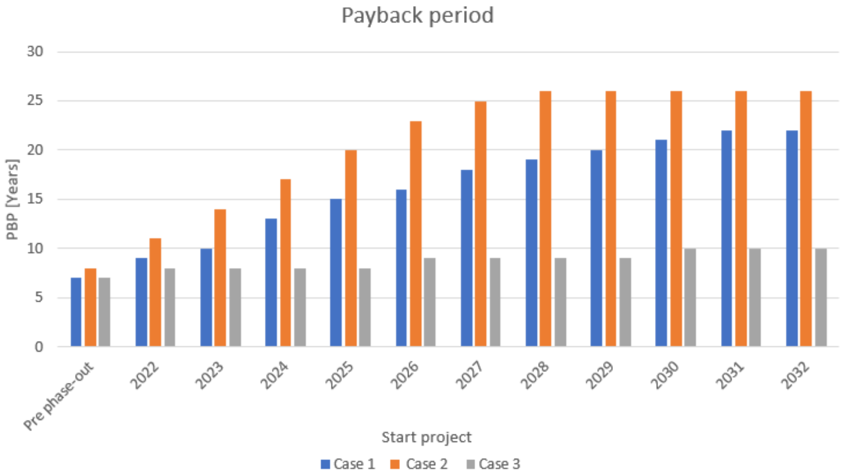


Figure 7: PBP of projects for different starting year

The results of the CBA can be found in Tables 19, 20 and 21.

Start date	**NPV**	**IRR**	**PBP**
Pre phase-out	€ 9,384.82	15.02%	7
2022	€ 2,133.18	7.51%	9
2023	€ 1,636.36	6.37%	10
2024	€ 1,178.00	5.33%	13
2025	€ 759.21	4.42%	15
2026	€ 381.11	3.62%	16
2027	€ 44.88	2.96%	18
2028	€ -248.28	2.40%	19
2029	€ -497.14	1.96%	20
2030	€ -700.42	1.61%	21
2031	€ -856.82	1.36%	22
2032	€ -965.00	1.19%	22

Table 19: CBA case 1

Start date	**NPV**	**IRR**	**PBP**
Pre phase-out	€ 12,696.34	12.34%	8
2022	€ 1,509.75	4.92%	11
2023	€ 711.84	3.83%	14
2024	€ -77.46	2.77%	17
2025	€ -857.90	1.75%	20
2026	€ -1,629.24	0.81%	23
2027	€ -2,320.91	0.04%	25
2028	€ -2,923.98	-0.59%	26
2029	€ -3,435.92	-1.07%	26
2030	€ -3,854.10	-1.44%	26
2031	€ -4,175.85	-1.70%	26
2032	€ -4,398.39	-1.88%	26

Table 20: CBA case 2

Start date	**NPV**	**IRR**	**PBP**
Pre phase-out	€ 4,504.71	15.02%	7
2022	€ 3,012.95	12.45%	8
2023	€ 2,910.75	12.05%	8
2024	€ 2,816.45	11.68%	8
2025	€ 2,730.30	11.33%	8
2026	€ 2,652.52	11.00%	9
2027	€ 2,583.36	10.71%	9
2028	€ 2,523.05	10.45%	9
2029	€ 2,471.85	10.23%	9
2030	€ 2,430.04	10.05%	10
2031	€ 2,397.86	9.90%	10
2032	€ 2,375.61	9.80%	10

Table 21: CBA case 3

The CBA indicated that PV-panels will become much less profitable with the phasing out of the net metering, but will remain profitable until a project start in the around year 2025. Note that, because of the assumption of static panel prices the calculations with late start years are very pessimistic. Furthermore, a low self-consumption is currently compensated for with net metering, but this will not be the case in the future. Seeing case 2 and 3, it is apparent that self-consumption will be much more important in the future.

B.1.2 Technical solutions

In this section, several possibilities to increase self-consumption will be looked into. As mentioned in the introduction of this chapter, unused energy can be stored to be used at a later time or energy usage can be increased during peaks of electricity production. First, storage solutions will be described, then solutions involving load shifting are explored.

Storage solutions
The intermittent nature of renewable energy generation leads to the production and consumption of energy not always lining up. In the case of PV-panels most energy is generated around noon, but the consumption in households is generally highest in the morning and in the evening. When the scope is broadened to a full year, the most energy is needed during the winter, while the most energy is produced in the summer. The former problem is solved with medium-term storage (1-10 hours) and the latter with long term storage (50-500 hours) [41].

Energy can be stored in many different ways. For residential applications, electrochemical, chemical and thermal energy storage are best suited. An overview of the different storage technologies is presented in Figure 8.

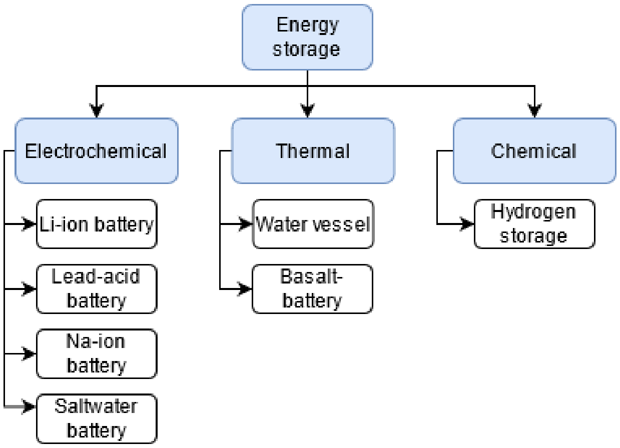


Figure 8: Possible storage solutions

For this report, the focus is put on bridging the gap between daily fluctuations in demand and generation. This means storage for a timescale of 1 to 10 hours is needed. The considered storage technologies will be further elaborated below.

<u>Electrochemical energy storage</u>
In electrochemical storage, electrical energy is stored and released through chemical red-ox reactions. The details of these reactions will not be explained in this report, because the focus lies on the application of the technology.

In the following, four types of batteries will be explored, and their advantages and disadvantages will be given.

Li-ion battery
Due to it's wide application in other fields like portable applications and electric vehicles, the lithium-ion (Li-ion) battery is the most technologically advanced battery technology. For home storage this battery is well suited, because is characterised by a high energy density, a high round trip efficiency and a long lifespan. However, due to safety issues like overcharging, over discharging and thermal runaway, a sophisticated battery management system is needed, which drives up the price.

Although Li-ion batteries are the most cost effective per cycle at the moment[42], a point of consideration is the high demand of lithium. Even though the physical scarcity is less problematic than initially expected, some experts expect supply chain issues leading to increasing prices in the future [43]. On the other hand a high demand will likely drive new developments in mining, technology and manufacturing which might increase the cost effectiveness.

Another downside of Li-ion batteries, is the controversial environmental effect. If the batteries are not properly disposed of the highly reactive materials can damage the environment. Furthermore, recycling is very complex, due to for example the toxic materials.

Lead acid battery
An older and more developed technology is the lead acid battery. These batteries are mainly used for car starter batteries, however due to the low costs and a simple design they are also suitable for home battery storage. There are two types of lead acid batteries: Flooded (FLA) and valve regulated (VRLA). The flooded version is cheaper, but it must be kept in a ventilated room and needs frequent maintenance. Due to the high toxicity of lead the recycling-methods of this battery are highly developed. Unfortunately, the low scarse energy density makes installations heavy and bulky. The technology has a low Cycle life and a bad Depth of Discharge (DoD). These disadvantages have led to the share of existing installations being replaced by Li-ion batteries [42].

No commercial home energy storage systems using this technology are available.

Sodium-ion battery
In order to decrease the dependency on Li-ion batteries some researchers are betting on the Sodium-ion (Na-ion) technology. This technology is very similar to Li-ion, but instead of lithium ions, sodium ions are used as charge carriers. The scarce and toxic materials needed for Li-ion batteries are not necessary for the Na-ion technology, especially the main component Sodium is abundant. The Na-ion technology could make the batteries much cheaper.

The reason Na-ion batteries aren't available on the market yet is the absence of a suitable anode, resulting in a low energy density and a low amount of cycles. Although multiple companies are developing commercial solutions, no Na-ion batteries are available on the market yet. [44]

Saltwater battery
A very novel technology is the saltwater battery. This is an aqueous version of the Sodium-ion battery. The most promising aspect of this technology is the materials. The battery mainly consist of fresh and salty water and the other materials like manganese oxide are neither toxic nor scarce. The materials are also non-flammable, there is no risk of thermal runaway and no danger when the battery is over-charged. This makes the battery very sustainable, safe and easily recyclable.

A drawback of this technology is the low energy density, leading to the battery being about twice as heavy as a similar Li-ion installation. This also results in more material being needed, increasing the price. Another issue is the low C-rate, resulting in a low power output.

In Table 22, some general specifications of the battery technologies are given.

Table 22: Overall specifications battery technologies

Battery	**Li-ion**	**Lead acid**	**Sodium-ion**
Nominal voltage [V]	3.6	2.1	3.5
Specific energy [Wh/kg]	140-230	30-40	75-150
Energy density [Wh/L]	270-350	60-75	250-375
Round trip efficiency [%]	85-90	75-80	¡92
DoD [%]	100	70	100
Self-discharge [%/month]	1.5-2	9-15	n.a.
Cycle life [cyles]	1000-5000	500-2000	± 1000
Energy cost [€/Wh]	0.4-0.8	0.08-0.17	n.a.

Thermal energy storage

Another method of storing energy is thermal energy storage. Thermal energy storage can be divided up into three categories:

- Sensible heat storage, where heat is stored in a temperature difference of a material.
- Latent heat storage, where heat is stored within a isothermal phase transition.
- Chemical heat storage,where heat is stored in a reversible chemical reaction.

The heat that can be stored is taken from the environment using solar-collectors or by cooling the residence during the summer. Further electricity from PV-panels can be converted to heat using an electrical resistor or a heat pump.

Hot water storage tank

An example of sensible energy storage is having a domestic hot water storage tank. Here hot water is stored in an insulated vessel. Water is a favourable storage medium, because it has a high heat capacity and can directly be used for domestic hot water applications, or the heating system of a house. The operating conditions are constrained by the freezing and boiling point. In combination with a heat pump a hot water reserve can be generated, when excess electricity is available from the PV-system.

Basalt battery

A very simple method of storing heat is with a Basalt-battery. A well insulated container is filled with basalt pebbles and a network of pipes. The basalt is heated up to 500 °C using electrical resistors. The 'battery' is discharged by flowing air or water through the pipes. According to the inventor the costs are about 0.02 [€/kWh] [45]. The system is suited for seasonal storage instead of compensation for daily fluctuations. This is a very new technology, currently the first implementation is being built.

Chemical energy storage

Hydrogen energy storage

For hydrogen energy storage (HES) excess electricity is used to turn water into hydrogen and oxygen using electrolysis. Later, when there is a demand for electricity hydrogen gas can be used to generate electricity using a fuel cell. Alternatively, hydrogen gas can be burned for cooking or in boilers. HES has the biggest gravimetric energy density $[J/kg]$ of all energy storage solutions mentioned here. However, the volumetric energy density $[J/m^3]$ is very low at ambient conditions, resulting in the gas needing to be compressed, liquefied or bound to another chemical component. Once stored the energy losses are minimal making HES ideal for seasonal energy storage.

A large downside of HES are the double losses when converting electricity to hydrogen and back. Electrolyser efficiencies range from 65 % to 85% [46] and fuel cell efficiencies range from 40 % to 60 % [47]. Currently, the HES for home storage is not viable compared to battery storage, because of the high costs of a hydrogen system, a reduction of 25% electrolyzer costs is needed to have similar results [48]. For this reason hydrogen storage won't be further explored.

Load management and smart grid solutions

In the introduction of this chapter, load shifting has been briefly described as the shift in time of specific loads, in order to match the supply of a solar panel for example. This concept is also described by the names demand-side-management (DMS) or load management system.

In a broader perspective, this concept can be applied to grids of all sizes. For example in the low voltage network, to which households are connected, the network operators could incetivise consumers to change their consumption behaviour through time-of-day pricing [49]. Furthermore, flexible pricing could be established with two-way-communication between the supplier and the consumer. This could make it possible for consumers to use electricity at the lowest possible price, if they are flexible about the time of use. The consumers can lower their electricity bill by changing their consumption habits, while the network operator profits from loads being shifted away from peak hours, or to a time where production is particularly high. This becomes increasingly important with the growing share of renewable energy sources, which are intermittent in nature, and can therefore not be controlled.[50]

Smart grids

This new kind of electricity grid with two-way communication is called a smart grid. In this decentralised system, every component acts as an agent of it's own. Every agent monitors and controls the corresponding component, and communicates with other agents. Therefore, these systems are called Multi-Agent Systems (MAS). [51] Systems like 'PowerMatcher' can be used to balance production and consumption based on the economic principle of demand and supply. Every agent, producer or consumer, can express his willingness to consume or produce in the form of a bid. For example, an appliance that needs to run at all times, will buy energy no matter what the price is, while an appliance that can be flexibly used will only want to run, when the price is low. A PV-system will produce electricity independent of the current price, simply when the sun shines. An agent can also vary the amount of power consumed or produced depending on the price. The curve that shows the power consumed according to price is called a bid-curve. The bid-curve can be updated based on the state of an appliance, for example a heat-pump might have a different bid-curve, based on the current temperature in it's hot water vessel. The bid-curves of all the agents in a system are aggregated, and the so called market equilibrium price is determined. That is the price for which the supply exactly matches demand at that moment in time. The amount of power that corresponds to the current price will then be allocated to every agent.

Figure 9 illustrates the principle of the bid curves, and the market equilibrium price. The agents act autonomously, based on the users preference. The most obvious goal might be to reduce the costs, but it can for example also be to use as much green energy as possible, or to reduce network congestion. [52]

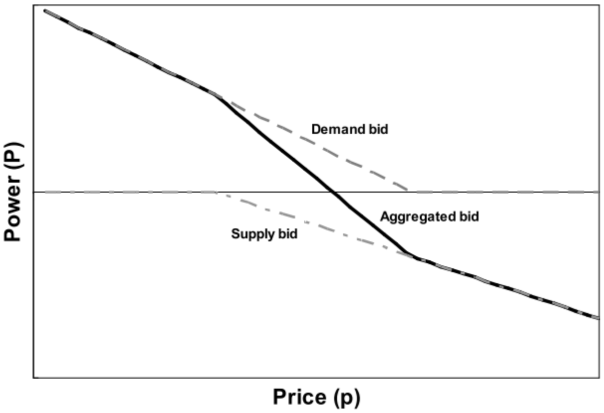


Figure 9: Example for bid-price-curves for an energy consuming device (dashed line) and a energy producing device (dashed dotted line) and the resulting aggregated bid-price-curve (solid line). The point where the line crosses the axis, where P=0, is the equilibrium point where the demand matches the supply.[53]

In addition to large scale applications, smart grids can be applied at a smaller scale, for example at neighborhood level. This kind of small grid is called a micro-grid, which Graaf [51] defines as 'decentralised energy grid that can balance supply and demand locally through the utilisation of distributed energy resources'. Although micro-grids are not very common yet, there are several examples of innovative projects using micro-grids in the Netherlands, that reach varying levels of self-consumption and self-sufficiency. A few examples are the ecovillage 'Aardenhuizen' in Olst, the floating neighbourhood 'Schoonschip' and the 'Republica papaverweg' both in Amsterdam-Noord.[51]

While smart grids are an interesting development, not many examples, where this is already being used, can be found. For this reason, we turned to Han Slootweg (Director of Asset Management at Enexis and part-time professor at the TU/e) to hear about the expectations of network operators like Enexis regarding the smart grid technology. According to Han Slootweg, it is not likely that this technology will be applied at a large scale in the near future. The necessary regulations and tariff structures are not yet in place, and the two way communication technology is not ready. He sees far more potential in home battery storage in combination with residential load management. For this reason the focus of the report will lie on load management on a small scale, specifically in residential buildings. Here the attempt is to balance production and consumption locally. Note that principles of a smart grid can also be used at a small scale.

In the next section, the scope will shift from a neighborhood level down to a household level. Since on this level load management can be used to optimise, for example, the self-consumption of a single household because no complex load management system has to be in place.

Load-management on a household level

Household-level load management can be practiced on a large spectrum of complexity from very simple to highly complex and intelligent. The simplest way to increase self-consumption by shifting loads, would be to manually start appliances during a time of the day, where it is known that the electricity production of the solar system is high. No investment costs are linked with this behavioural change, but the possible improvements might be limited. For example a lot of people are at their workplace during the day, and can't manually start an appliance. Another way, that is slightly more complex would be to schedule loads in advance, for a time, where the production is expected to be high. The investment costs are no longer zero, but still rather low, and the outcome is more promising than with manual starting of appliances. However, no reaction to real-time production is possible, which limits the potential of this solution. On the other side of the spectrum, there are highly intelligent systems using complex algorithms, like neural networks, to manage loads using the weather forecast, learned predictions of consumption behaviour, requests by the user, etc. These very complex systems, come with higher investment costs, but especially when used in combination with storage, can deliver very good results.

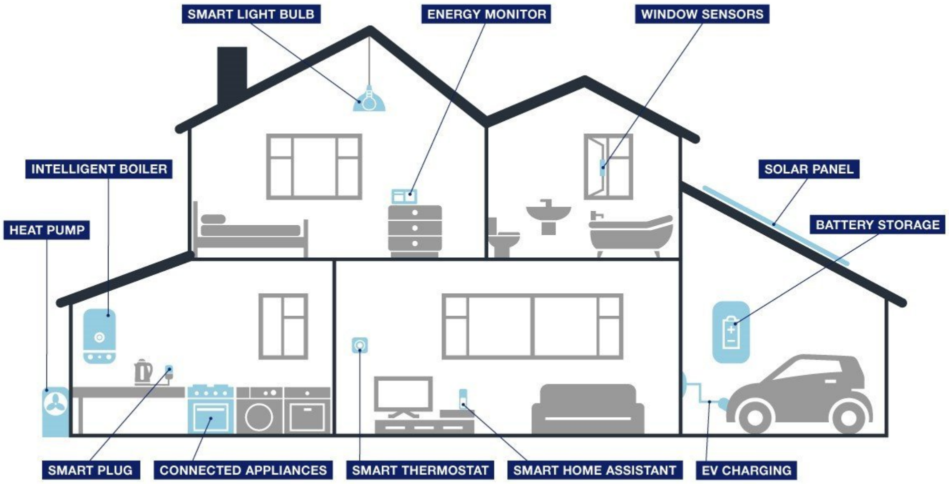


Figure 10: Representation of a 'smart home' [54]

For example, Barelli et al. [55] present a 'Residential micro-grid load management trough artifical neural networks'. The system includes a PV-system and energy storage. Programmable loads were identified, such as the washing machine, the dishwasher, the dryer, the daily cycle of the fridge, and many more. The weather forecast is used to predict the production of the PV-system, and the loads are scheduled according to a certain control logic. A model developed using the software Simulink, was used to simulate cases based on real data, and the system was able to reduce the energy consumption from the grid by between 18% and 38% depending on the season. It is important to note, that these results come from an academic research paper, and not from an actually implemented system.

Further, an important aspect that has a strong influence on the potential of load management solutions is the number and type of programmable loads that are present in a house. Certain loads that were traditionally fueled by fossil fuels, are now slowly being replaced by electric appliances. Examples for this evolution are heat pumps, that can replace gas fired boilers, or electric vehicles, replacing traditional vehicles. Both of these loads are not only partly programmable, but they also represent a significant part of the total electricity consumption of a household. On average, a household has an electricity consumption of about 3000 kWh per year in the Netherlands [56], while the average energy consumption of a heat pump is about 4000 kWh annually [57], which means that the electricity consumption more than doubles, with the use of a heat pump. If we consider the case of a person who drives 15000 km a year, with an average consumption of an electric vehicle of 15 kWh per 100 km, the annual electricity consumption of the EV is 2250 kWh [58]. This example illustrate, that an EV is also a major consumer in a household.

Vanhoudt et al. [59] analysed the potential of a heat pump with thermal storage buffer to reduce power peaks and increase self-consumption of renewable energy systems for a household in Belgian climate. To this end, a common heat driven control strategy for the heat pump is compared to an active control strategy using a multi-agent control system. Four agent were used for the heat pump, the renewable energy source, the electricity grid and the uncontrollable load of the house. An average winter week as well as the coldest winter week were modeled. The self-consumption for a case with a PV-system was increased by 15.1% for the coldest week and by 29.2% for the average week for the active control, compared to the common control. This is a significant improvement of the self-consumption considering, that the heat pump is the only shiftable load in this case. The downside of the active control is an increased overall electricity consumption of the heat pump of 8-12%. The reason for the increased consumption is the higher number of switches resulting from the active control. Every time the heat pump is switched off, the fluids in the circuits cool down. Further, there are unavoidable start-up losses when switching it back on and the circulation pumps always run about two minutes before the heat pump is started and after it is turned off. Nevertheless, injection and extraction of electricity from the grid was reduced with active control. This shows potential of load shifting, to increase self-consumption, when applied to a heat pump.

Unfortunately, the heating demand is highest in winter, while the production of solar energy is highest in the summer, which leads to little overlap of the heat pump power consumption and the solar power production. [51] Graaf et al. [51] also found that it can be very attractive for peak shaving in the summer to use a cooling system. However, while this increases self-consumption, it increases the overall energy usage.

The use of intelligent software to charge electric vehicles can also greatly increase the local self-consumption, and reduce peak demand. [51] However, the potential of EVs to contribute to a higher self-consumption strongly depends on when and for how long they are plugged in [60]. Gudmunds et al. [60] conducted a study to determine how the introduction of an EV affects self-consumption and self-sufficiency of a household with in-house electricity generation by a PV-system and if an EV can complement or replace a stationary battery. In this study, both EVs with and without vehicle-to-home technology (V2H) were considered. A car with V2H can discharge electricity back to the household, while it is plugged in. The main difference between this study an other similar studies, is that real-time driving data from EVs was used, which includes information on when, for how long and at what state of charge the vehicles were plugged in. Coupled with measured household electricity profiles, and modeled production profiles, more than 400 different combinations were simulated. A graphical representation of some of the median results are presented in Figure 11. On the horizontal axis, the 'PV panel ALR' is a measure for the size of the PV-system (W_p) compared to the annual household load (W). It can be observed, that both the cases for an EV with V2H and without lead to an improved self-consumption compared to a case without any storage. The advantage of the V2H technology grows with a growing PV-system size. This study illustrates that an EV has the potential to increase the self-consumption significantly, but the actual advantage is very case-specific, and varies a lot depending on users behaviour.

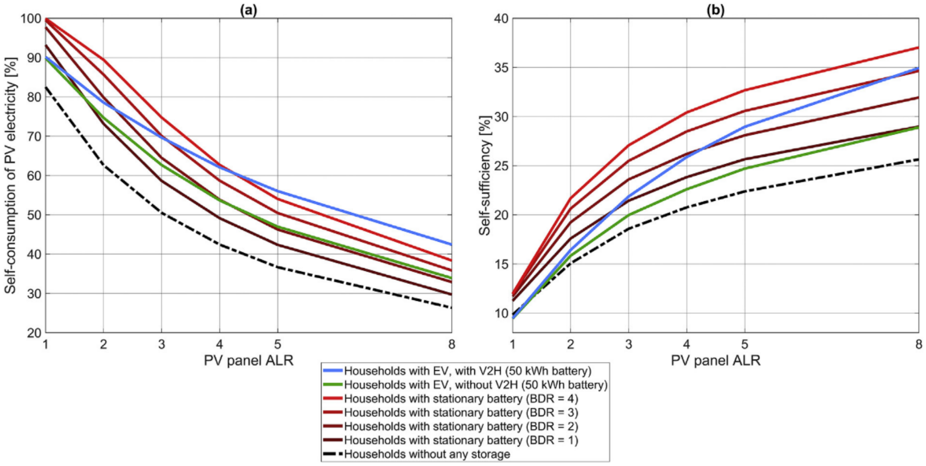


Figure 11: Results for self-consumption and self-sufficiency for different PV-system sizes and scenarios [60]

This part considers more commercial solutions, that are actually available to purchase instead of theoretical solutions that are not readily available. Smart heat pumps and EV charging stations are becoming more widely available, but systems that allow a consumer to connect a larger number of appliances to the same system, are still rather rare. One example of such a system, that is available in the Netherlands, is a product called Smappee. It allows a consumer to connect a PV-system, a battery, an EV charging station and other smart appliances to one single control system. It works with a number of third-party smart appliances, or it can make appliances 'smart' by adding a smart switch, that monitors the consumption of the appliance and can switch it off remotely. Further, the available solar electricity is forecasted, and used to improve the control. The whole system can be managed from a smartphone app. [61] To use this system, some hardware needs to be installed in the house. The installation costs of the system are around 350€, according to the dealership AirTeq, who provided this price upon request.

No similar system was found to be available in the Netherlands at this moment. This is not surprising, because the current net metering scheme leaves no need for such systems, as there is not yet an incentive for prosumers, to use more of their own electricity. However, it is likely that, once the end of the net metering scheme approaches, more and more companies will penetrate this market, as it will then become financially interesting for households, to invest in these systems. This might also lead to lower costs for consumers, as has been the case for many technologies, when they are produced at a larger scale.

Finally, a difficulty arises, when not a single household is considered, but a apartment building. If a PV-system investment includes several parties, the profit has to be divided fairly between these parties. If self-consumption plays a role in the profit maximization, like it is the case if the net metering scheme vanishes, then this become more complicated.

Two potential options have been identified to address this problem. The first option is to only measure the self-consumption for the entire building and divide the profits proportionally to the investment of the different parties. In that case, the incentive to increase self-consumption is limited for each party, because the profit generated by it, is divided between all parties. This option is however not yet applicable, because the legal framework does not yet exist. The second option is to monitor the self-consumption for each party individually with a a smart meter in every apartment, and divide the profits exactly according to each parties self-consumption. While that leads to an increased incentive to improve self-consumption, it has the downside, that profit calculations become a lot more complicated and hardware and software to complete the task are necessary.

B.2 Methodology

B.2.1 Multi-criteria analysis for solutions to compare self-consumption

In order to compare different solutions to increase the self-consumption of electricity generated by a PV-system on an apartment building, an MCA is conducted. An MCA is a decision making tool often used for complex, multidisciplinary problems. The analysis takes a number of different indicators into account, and thus represent different stakeholders and interests. Weighing factors for each criterion represent the relative importance of each aspect. This relative importance is often subject to debate, and might vary amongst different stakeholders. Several alternative options can be scored for each of the chosen criteria, which will then lead to an overall score for each alternative. The alternative with the highest overall score is considered the best solution under the given priorities.

The MCA for this project is conducted for a specific building and a specific PV-system type, since the costs and results of different solutions to increase self-consumption are highly dependent on case specific values, like the PV-system size or the energy consumption. The outcomes are therefore not necessarily applicable to all situations, and must be handled with care.

The case that will be considered is that of the medium sized building from the previous part, using a configuration, where the communal utilities are supplied by the PV-system, and the surplus is supplied to a number of apartments. Some of the measures to increase self-consumption will be related to a single apartment, and some of them will be related to the communal connection. The results for all solutions will be provided as total amounts for the whole building complex. This means for solutions for a single apartment, it is assumed that the solution is implemented in all the apartments connected to the PV-system.

Once all the qualitative and quantitative data is collected, these two types of criteria are first evaluated separately. For the qualitative data, a standardised form is determined, to make the criteria comparable. The standardised for is a value between 0 and 1, where one corresponds to the best value, and 0 to the worst value. It is determined by dividing the difference of the value and the lowest value in that category, by the the difference between the highest and the lowest values of the category. From this set of standardised data e, the qualitative dominance scores are determined. The dominance score a of the alternative i over the alternative i' is calculated as follows, with j being the index of the criteria, w being it's weight and N the number of criteria:

$$a_{ii'} = \sum_{j=1}^{N} = w_j * (e_{ji} - e_{ji'}) \tag{13}$$

Next, the dominance scores for the quantitative data are calculated. This calculation only considers if one option is better or worse in on category, and no specific difference, like for the qualitative data. The dominance scores are calculated as follows:

$$a_{ii'} = \sum_{j=1}^{N} = w_j * sng(n_{ji} - n_{ji'}) \tag{14}$$

Finally, the qualitative and quantitative dominance scores are added up leading to the overall dominance scores, which can be used to identify the best alternative.

B.2.2 Solutions to be compared

The solutions that will be compared in the MCA are the following:

- Li-ion battery for a single apartment
- Salt-water battery for a single apartment
- Li-ion battery for communal connection
- Communal EV-charging station

- Communal heat pump
- Home energy management system

B.2.3 Selection of criteria and weights

To compare the solutions presented above, an MCA is used in the way that is described at the beginning of this chapter. To do this, different criteria have to be chosen to base the assessment on. To come to a list of criteria, a small literature review of case studies using a MCA is performed ([62], [63], [64], [65]), which yielded insights in common indicators that are used in an MCA. First, based on the assessed literature, it is decided that four categories of criteria are most relevant: economic criteria, environmental criteria, practical criteria and health and safety criteria. Second, also based on the assessed literature, individual criteria are chosen for every category.

The economic category assesses the financial aspects of the process. Criteria chosen for this category are the additional cost of investment (in Euro (€)), which is the amount of money needed to realize the solution in question. Also, the internal rate of return for the whole project (in a percentage (%)) is a relevant criterion, which is the internal rate of return for the total system including the specific solution and the solar system. The last relevant criterion is the pay-back period of the whole project (in years), which is the period in which the investment of the whole system earns itself back.

The environmental category concerns all the environmental criteria that are involved with a specific solution. The first criterion is the amount of CO_2 saved per year (in Kilogram), which assesses the decrease in CO_2 emissions that is obtained by implementing the solution. The second criterion in the environmental category is the need for rare resources, which is a qualitative criterion. This takes into account if rare resources are used to produce or operate the solution. The last criterion in this category is the waste production, which is also qualitatively assessed. This criterion assesses the amount of waste that is produced during production, operation or at the end of life of the product.

The category of practical criteria contains four criteria. The first criterion is the space requirement (qualitative), and this criterion assesses the space that is needed to install and operate the specific solution. The second criterion is the increase in comfort (qualitative). This indicates whether stakeholders experience an increase in comfort due to the application of the specific solution. The third criterion is the increase of independence (qualitative). This criterion assesses whether or not stakeholders perceive an increase in independence from other parties, for example, if stakeholders do not have to rely on external produced electricity, but can use their own generated electricity. The last criterion in this category is the necessity of maintenance (qualitative), which indicates whether a solution needs maintenance or not.

The last category, health and safety, assesses the factors concerning the health and safety around the installation and operation of each solution. This category contains two criteria. The first criterion assesses the air quality improvement (qualitative), which means that it is assessed whether a solution yields a direct local air quality improvement, for example less emissions of pollutants. The second criterion assesses the risks for hazards or accidents during the installation or operation (qualitative). This includes for example explosion danger or fire danger.

Now the categories and criteria are determined, the relative importance for every indicator should be determined. This importance can be incorporated in the model by including a weighing factor to every criterion, as discussed earlier. The weights for these cases are determined by the project group itself, during a discussion about the relative importance of every criterion. The goal was to view these indicators from different perspectives, but mainly from the VvE participants in general. The weight for every category and every individual criteria can be found in Table 23. It may be clear that these weights are subjective, and are really sensitive to the person who decides on them. Different persons, with different stakes or expertise might look differently at this problem.

Table 23: Criteria and weights used for the MCA

Category	Criteria	Dimension	Weight	Sum per category
Economic	Additional cost of investment	€	5%	**50%**
	IRR for whole project	%	30%	
	PBP for whole project	years	15%	
Environmental	kg CO2 saved per year	kgCO2	10%	**20%**
	Need of rare resources	qualitative	5%	
	waste production	qualitative	5%	
Practical	space requirement	qualitative	5%	**20%**
	Increased comfort	qualitative	5%	
	Increased independence	qualitative	5%	
	necessity of maintenance	qualitative	5%	
Health and safety	air quality improvement	qualitative	3%	**10%**
	risk of hazards or accidents	qualitative	7%	

B.3 Data collection

B.3.1 Li-ion battery for a single apartment

A Li-ion battery used as a home storage system for solar energy might be the most common solution to increase self-consumption. Since the tariff structures and regulations for collective battery usage for several apartments are not in place yet, an individual battery per apartment will be considered. First, the appropriate size for such a battery needs to be determined. According to Schram et al. [66], the economically optimal battery size is 0.75 kWh per MWh of consumption, if the PV-system size is 1 kWp per MWh consumption. Since in our case is reasonably similar to this (2.375 kWp vs. 2.5 MWh), an optimal battery size of 1.875 kWh is chosen. Three batteries available on the market with a usable capacity close to the optimal capacity were compared. The results can be seen in Table 24. The usable capacity, price, power and warranty were retrieved from Solar Quotes [67]. The price per kWh and per warranted year was calculated in order to compare the batteries. The first option turns out to be the most cost effective, because it has a much longer warranty than the the other options. The price of an inverter, that has to be purchased separately is assumed to be about €500 [68], and the installation costs are assumed to be around 30% of the material costs [66]. This leads to the total price listed in the last row of the table. To calculate the total investment costs, it is assumed that a battery is installed in every of the 15 apartments connected to the PV-system. The total investment costs are thus €46980 .

Table 24: Comparing different options for small Li-ion batteries

	Zenaji Aeon	**Pylontech US2000B**	**SolarWatt MyReserve Matrix**
Usable storage capacity [kWh]	1.93	2.16	2.40
Price (excl. inverter & inst.) [€]	1909	1280	1280
Power [kW]	2.4	2.00	0.80
Warranty [years]	20	7	5
Price per kWh per year warranty [€]	49.46	84.66	106.67
Inverter price approximation [€]	500	500	500
Total price [€]	3132	2314	2314

Luthander et al. [37] reviewed a number of studies about increasing self-consumption through the use of battery storage. For the combination of PV-system size and size of the battery storage used in this case, an average increase of self-consumption of about 20% is found. This value is confirmed by a study of Quoilin et al. [69]. Note that this value for the increase in self-consumption is only for the part of the system linked to that particular apartment.

Next, the IRR and the PBP, for a solar system project, with the additional investment for battery storage in the participating apartments are calculated. In order to do this, the CBA-model from the previous part is used and slightly modified to fit the new boundary conditions. The additional investment costs (Adjusted for the lifetime of the PV-system) and the increase of self-consumption are included, and the only subsidy used is the SCE, since it is very new, and likely to continue for some time. The result are an IRR of 11.45% and a PBP of 9 years. It is important to note that these values are lower than for the base case without the storage, where an IRR of 15% and a PBP of 7 years was found. Investing in this type of battery is therefore not profitable in this case.

In the following, the scores for the environmental criteria are determined. The first environmental criterion is the amount of CO_2 that can be saved by implementing the given solution. In order to calculate the difference between the CO_2-emissions before and after implementing the measure, the initial emissions are first calculated. In this case, the emissions for a single apartment with and without a battery are compared. Without the battery, it is assumed, the the self-consumption is 30% [69]. This means that 70% of the energy is taken from the grid. Considering that the energy intensity of the electricity mix in the Netherlands is 0.45 kgCO_2/kWh [70], the emissions resulting from the amount of electricity taken from the grid are 792 kgCO_2 per year.

In the case with a battery, only 50% of the used electricity is taken from the grid. This corresponds to 566 kgCO_2 per year. Since the battery has an efficiency of 95%, the amount of electricity used increases, to cover the losses of the battery. 20% of the total electricity flows through the battery, and 5% of this amount is thus consumed additionally. This leads to an additional 11 kgCO_2 emitted. Finally, the production of Li-ion batteries is highly energy intensive, namely it is estimated that 39 kgCO_2/kWh are emitted for the production of the battery. If this is spread over the expected lifetime, the additional amount emissions for the production amount to 3 kgCO_2 per year. This leads to a total of 580 kgCO_2 per year, which is 212 kgCO_2 less than is the reference scenario above. In total, for all the apartments, 3180 kgCO_2 are saved per year.

Li-ion batteries are constructed of some different metals, such as copper, lithium, cobalt, aluminium, iron and nickel [71]. These metals have to be mined, which is typically a process that costs a lot of energy. Also, the supply of these metals is limited, so scarcity of for example lithium could be an issue when mass producing Li-ion batteries. Due to the need of these metals, the Li-ion battery is considered to have a high need for rare resources.

In addition to the need of metals, other materials such as plastics and organic chemicals can be used to produce a Li-ion battery [71]. These batteries contain enough of these materials to make recycling possible. However, the recycling rate is still very low, which means that only few batteries are recycled [72]. At this moment, the waste production is considered to be high for Li-ion batteries, but this will decrease in the future due to increased recycling efforts [73].

Li-ion batteries have a relatively high energy density, which means that they do not have to be big to store the needed electricity for one household. For example, the previously presented example battery Pylontech US2000B has a size of 44 x 41 x 8.9 centimeter [74], which means that it does not need much space and that it can be placed almost everywhere in the apartment. Based on this, it is concluded that these batteries do not have a high space requirement.

The battery provides electricity storage, which means that electricity generated by the PV-system can be stored and used at a later moment. For the user, there is no difference between electricity that comes from the grid an electricity that comes from the battery. Based on this, it is concluded that the battery will not result in an increase in comfort for the users.

However, since the battery provides the possibility to use electricity generated by the PV-system at a later time, for example during the night, the installation of a battery increases the independence of the users. The users of the battery are less dependent on the central electricity grid, and can better rely on their own electricity generation system.

Li-ion batteries do not need much maintenance [75]. However, it is advised to check all the connections and clean the battery once a year.

The installation of the battery yields no direct local air quality improvement. It facilitates the use of own generated electricity, but it does not replace a system that pollutes the air for example.

The Li-ion batteries contain different chemicals, which might result in dangerous situations. Li-ion batteries are relatively safe when used in the proper way, however, there is a risk that unwanted events occur. For example, when the battery overheats, thermal runaway might occur which leads to a fire. Fire in li-ion batteries is hard to extinguish and the release of toxic materials, which can result in dangerous situations [76]. As mentioned, the chance that unwanted event occur when used properly is small, however, due to the possible severe consequences, the risk of accidents is indicated as high.

B.3.2 Saltwater battery for a single apartment

A new upcoming battery technology, is the saltwater technology. The company Green Rock sells such batteries in different sizes, of which the smallest has a capacity of 5 kWh. This is considerably larger than the optimal size determined previously, but since no smaller saltwater battery is available, this one will be considered. The price of the battery is about €6750. If we assume again, that the installation costs are around 30% of the purchase costs, the total costs for this battery are €8775. For 15 apartments, the total investment costs are thus €131625 .

The self-consumption increase that can be approximately reached with this battery size is 32% [69]. Note that this value for the increase is only for the part of the system linked to that particular apartment.

Further, the IRR and PBP are calculated for this case, using the same calculation as for the previous solution. An IRR of 4.55% and a PBP of 17 years is found. Again, it is important to note that these results mean that the project is less profitable with the battery, than without.

Next, the environmental criteria are scored. In order to calculated the amount of CO_2 that is saved in this case, that same calculations are made, as that for the previous case. The self-consumption increase for this battery is larger, so only 38% of the electricity is taken from the grid, which leads to 430 kgCO_2. The efficiency of the salt-water battery is 88.5% resulting in additional emissions of 92 kgCO_2 for the additional energy use. Finally, the emissions related to the production are taken into account. The salt-water technology is a relatively new technology, which means that little literature is available about it at this moment. For this reason, no data on the production footprint of this type of batteries was found, and it was assumed that the emissions are the same as for Li-ion batteries. Consequently, it was calculated, that an additional 13 kgCO_2 per year need to be considered for the production. The total emissions per year for this case are 522 kgCO_2 per year, which is 270 kgCO_2 less than the base case. In total 4052 kgco_2 are saved per year.

The salt water battery typically uses less rare resources than, for example, a Li-ion battery. There are some metals used to produce a salt water battery, such as zinc and copper [77]. These materials are quite scarce (40 years of copper reserves [78], and 17 years of zinc reserves [79]). This means that there is some need for rare resources, but not as high as for example for a Li-ion battery.

In Europe, around 41% of the annual copper use came from recycled sources throughout the last decade [78], for zinc, this number is around 55% [80]. This means that many of these materials are already recycled, but there is still some waste production, this is again not as much compared to a Li-ion battery.

Salt water batteries need more space than, for example, Li-ion batteries. The size for salt water battery from Green Rock, that is used as an example in a previous paragraph is around 32.9 x 32.3 x 95.9 centimeter. This means that the space requirement is significantly higher.

For the same reasons as for the Li-ion battery, the salt water battery does not yield an increase in comfort. This is because the user does not experience any difference between using electricity from the grid or electricity from a (salt water) battery.

The salt water battery increases the independence since electricity, generated by the PV-system can be stored and used at a later moment. This means that one becomes less dependent on the central electricity grid. From this is concluded that the salt water battery results in a high increase of independence.

The salt water battery does not require any maintenance [81]. This means that no work or costs are involved in this.

The installation and usage of a salt water battery does not directly influence the local air quality. This is because the system does not replace another system that pollutes the local air.

Salt water batteries are a safe way to store electricity [82]. Salt water batteries are even claimed to be the safest option for electricity storage, since they are not explosive or flammable [81]. Therefore, the salt water battery is considered to have a low risk of hazards or accidents.

B.3.3 Li-ion battery for communal connection

In this case, a Li-ion battery storage for the communal part of the building is considered. Again, the optimal batter size is determined according to Schram et al. [66]. For this case, the result is an optimal battery capacity of 12kWh. Three batteries with a similar size, that are on the market are compared in Table 25. The usable capacity, price, power and warranty were retrieved from Solar Quotes [67]. For the first option the inverter has to be purchased separately, for an estimated price of €2000 [83]. As previously, the installation costs are estimated to be 30% op the purchase price. From the calculated price per kWh per year warranty, it is apparent, that the first option is the most economical, which will be considered for further analysis. The total investment costs if a battery is installed in every of the five buildings, are €41755.

Table 25: Comparing different options for large Li-ion batteries

	SunGrow SBR HV	**Opal Storage**	**Tesla Powerwall 2**
usable storage capacity [kWh]	12.8	11.7	13.5
Price (excl. inverter & inst.) [€]	5193	7614	8439
power [kW]	7.68	4.6	5
warranty [years]	10	10	10
inverter price approximation [€]	2000	0	0
price per kWh per year warranty	56.20	65.08	62.51
Total price [€]	9351	9898	10971

In this case, it is less straight forward, to determine the self-consumption increase, that can be reached, by installing the battery. The reason for this, is that no studies could be found about the load curves of the communal utilities, or the self-consumption related to it. In order to make an estimation about the possible increase of self-consumption, it was assumed, that the shape of the load curve of the communal utilities is similar that, that of a household. The reasoning behind this assumption, is that many of the communal utilities, like the stairwell lighting or the elevator are mostly used in the morning or in the evening, when inhabitants come or go. The highest consumption would then be in the morning and in the evening, just like for household load profiles. With this assumption, the results of Quoilin et al. [69] can be used again, and a self-consumption increase of 20% was determined. Note that this value for the increase is only for the part of the system connected to the communal utilities.

Further, the IRR and PBP of a solar system project with this kind of battery are determined, using the CBA model. The result is an IRR of 11.2% and a PBP of 9 years. Just as for the previous storage solutions, the battery does not make the project more profitable.

Moreover, the environmental criteria are scored for this solution. The amount of CO_2 saved is calculated by comparing the case of a building with a communal battery to a base case without the battery. The total electricity used for communal utilities is 16 MWh per year for each of the 5 buildings of the complex. For the base case we consider again, that the self-consumption is 30% meaning that 70% of the energy is taken from the grid. The emissions corresponding to this are 5069 kgCO_2 per year.

If a communal battery is used, only 50% of the electricity used is taken from the grid. The emissions for that amount of energy in the Netherlands are 3621 kgCO_2. As was the case for the small lithium ion battery, this battery has an efficiency of 95%, meaning, that an additional 5% of the electricity flowing through the battery is consumed. This leads to an additional 72 kgCO_2 par year. Furthermore, the production of the battery is responsible for another 33 kgCO_2 per year, if divided by the expected lifetime. The total emissions finally amount to 3727 kgCO_2 per year, which is 1343 kgCO_2 less than the reference case. In total this leads to 6714 kgCO_2 saved for the whole complex.

For this application, a same kind of Li-ion battery is used, except for this version being a bigger one, since typically more capacity is needed to power the communal utilities then is needed for powering an individual household. This means that the need for rare resources, waste production, increase in comfort, need for maintenance, air quality improvement and risks of hazards or accidents are the same, for the same reasons as described in the 'Li-ion battery per apartment' section. This battery typically is bigger than an individual battery, since more capacity is demanded. However, the space requirement has the same score for the communal Li-ion battery and the individual household Li-ion battery since the communal space is also assumed to be bigger than the individual household space. The increase in independence is scored one grade lower than it is for the Li-ion battery for an individual household. This is because it increases the communal independence, since the community as a whole is more independent from the electricity grid, but as an individual, one is still dependent of the central installed battery, and one is not individually independent.

B.3.4 Communal EV-charging station

An EV-charging station can be used to charge electric vehicles. This charging station will be connected to the communal electricity supply, so a part of the electricity generated by the PV-system can be used to charge EVs. The EV-charging station should be publicly available to maximize the usage and benefits. The charging station is equipped with an RFID card reader to make it publicly accessible and 3,7 - 22 kW charging power. This means the additional electricity is potentially sold to third parties. Platforms like for example E-Flux **E-flux** make it possible to easily manage the billing of such a system for a small fee, and potentially set different rates for inhabitants than for visitors. Such an EV-charging station costs around €1899 including installation [84]. It is decided that at each building of the apartment complex, two charging stations will be installed, which means that for the five buildings in total ten EV-charging stations will be installed, with costs estimated around €18990.

In the following, the self-consumption increase for this case will be determined. Here the same problem arises, as for the communal battery storage, since the EV charging stations are connected to the communal part of the system. Again, no studies have been found, looking at this specific problem. Roy et al. [85] analysed a residential building with 20 apartments, and a PV-system of 38.9 kWp, with different EV penetration rates in Belgium. For uncoordinated charging during the day, with 2 EVs, they found an increase of the total self-consumption of 2.4%. The building and system size are comparable to one of the five buildings in the considered apartment complex of the present study. However, in this case, the EVs are only connected to the communal consumption and not to the entire system. For this reason, an estimation is made that the absolute increase in self-consumption is the same as in the study, but it is presented as a percentage of the communal system. The result of this assumption is an increase of self-consumption of 3.9% for the communal system. Here it is important to note, that this is a very rough estimation, and that the value can vary a lot depending on the actual usage of the charging stations, which is hard to accurately predict.

Next the IRR and the PBP for a solar project with this type of EV-charging stations are calculated using the CBA-model. In this case not only the investment costs and the self-consumption are adapted, but the additional electricity use of about 3000 kWh/year [86] per charging station is included, as well as an additional cash-flow for the electricity sold at the charging station. It was assumed that the electricity is sold for 0.25 €/kWh (excluding taxation), which is a bit more than the price for grid electricity in our case (0.22 €/kWh), but a lot less than at commercial charging points, who charge at least around 0.30 €/kWh [87]. The reason for this is that is assumed that the charging point might be used primarily by inhabitants of the building itself. The result is an IRR of 16.44% and a PBP of 7 years. This solution is more profitable than the base case, even with this low price for the electricity sold. It is important to note, that the result is highly dependent on the price fixed for the electricity sold at the charging point.

The amount of CO_2 that can be saved by installing EV-charging stations is calculated as follows. The self-consumption for the communal utilities can be increased by 3.9% which means that only 66.1% of the electricity needed is taken from the grid. This means that 4787 kgCO_2 are emitted for the use of the utilities per building. On top of that, about 3000 kWh/year of consumption per charging station increase the overall consumption, which leads to another 1795 kgCO_2 produced. This electricity used by the EVs was however not consumed somewhere else. To take that into account the amount of emissions that would have been produced if the cars were charged with electricity form the grid only, which is 2716 kgCO_2, is subtracted. The total emissions per building are thus 3866 kgCO_2, which is 1203 kgCO_2 less than the base case. In total, for the whole complex, 6015 kgCO_2 can be saved per year.

EVs typically need some rare materials, such as gold or copper. However in addition to this, no rare materials are needed to produce an EV charging station. So the EV charging station has a relatively low need for rare resources.

The biggest waste stream that comes from an EV-charging station is electronic waste and plastic. Electronic waste is growing one of the biggest waste streams in society, and recycling remains a challenge, since electronic products are complicated and non-homogeneous [88]. Since EV-chargers contain no major harmful substance, but do contain electronic components, the waste production with an EV-charging station is evaluated as intermediate.

The EV-charging system on itself is small (for example 23 x 33.8 x 59 centimeter [84]). However, when an EV-charger is installed, typically one parking space is reserved only for EVs. This means that is not allow to use the parking space for a non-electric car. Based on this, it is concluded that the EV-charger has a moderate-high space requirement

The EV-charging station on itself does not increase the comfort of the inhabitants of the apartment building. However, the EV-chargers creates an option to charge electric cars for inhabitants of the apartment complex. This means that owners of electric cars could charge their car closer to their home, which can be seen as comfortable. It is assumed that the EV charging station yields a moderate-high increase in comfort.

In addition to the increase of comfort by charging electric cars at home, this option also allows people to make a choice between electric cars and fossil fuel cars. This increases the independence since people can choose whatever option they like, in addition to this, one can choose to not be dependent on fossil fuel providers, but to generate the electricity needed for electric cars themselves. This results in the assumption that the EV-charger yields a high increase in independence.

An EV-charger requires very little maintenance when the installation is done professionally [89]. For this reason, it is assumed that an EV-charger requires no maintenance.

The installation of an EV-charger creates the option to charge an electric car at that location, and also results in the fact that no fossil fuel car can be parked on this specific parking place. This basically will attract more electric vehicles in the neighbourhood, and decreases the place available for fossil fuel cars. In the end, this decreases the amount of fossil fuel cars, and increases the amount of electric cars, which means that some emissions of the fossil fuel cars are replaced by emission-free electric cars. However, since only two chargers per building, and in total 10 chargers for the whole apartment complex are considered, this effect is not on a large scale. Due to this, it is concluded that there will be some improvement of the air quality.

The EV-charger on itself is a device that transports electricity. This means that there are minor risks attached to the use of it, however these risks are low when the charger is installed professionally [90]. When the charger is used, it is typically used by an EV with a Li-ion battery. The risks of Li-ion batteries are discussed earlier in this section, on which we can concluded that this involves risks. However, since these risks mainly are involved on the side of the EV, the risk of an EV-charger is considered as moderate-high.

B.3.5 Communal heat pump

Heat pumps can be installed to replace the current central heating system. Heat pumps are powered by electricity, which means that they are a sustainable source of heat for the apartment complex (if the used electricity is produced in a green way). To estimate the costs and feasibility of such a heat pump system, Jelle van der Heijden, who is a junior designer for building appliances at Nelissen Ingenieursbureau [91], provided advice. It has to be mentioned that the numbers given in this section is a rough estimations, since the advice is based on basic assumptions in the industry, without seeing the actual case, so the numbers have to be treated with caution.

The decision has been made that and air-water heat pump would be the best option for the apartment complex, since this probably requires the least modification to the current system in the building. The assumption has been made that 40 Watt (W) of heating capacity is needed per square meter, and with 18 apartments per building, and an assumed apartment size of $130m^2$, a total heating capacity of 93600W is needed per building. To provide this capacity, two heat pumps are advised, to benefit from subsidies (€6000 per heat pump) and redundancy, because when one heat pump fails, the other one can still provide a part of the heat demand. The total heat pump system, including installation, changes to the building and subsidies will cost around €89850 per building, which is around €4992 per apartment, so for all the 87 apartments, this is around €434304. A complete breakdown of the total cost per building is given in Figure 12 in Appendix C

The increase of self-consumption related to the introduction of a heat pump, for different building types was studied by Williams et al. [92]. For the introduction of a heat pump with a heat storage and domestic hot water (DHW) production, in a building built around 2003, an increase of self-consumption of about 15% was found. Here, the same problem than for the EV charging stations comes up, since the findings in the study refer to the total system, and we are looking for the increase just for the communal part of the system. The same assumption is made, that the absolute increase is the same as in the study, but expressed as a percentage of the communal system. In this case, the result is a self-consumption increase of about 20% of the communal system. It is noted that this is again a rough estimation, and the real value might differ from it.

Further, the IRR and PBP for the central heat pump are calculated using the CBA model. The investment costs, the increased self-consumption, and an estimated 142500 kWh of additional electricity usage are added to the model. Moreover, the costs for the former heating system, that is now no longer needed, are introduced as a positive cash-flow. Assuming that the buildings were previously equipped with gas boilers for heating, the costs saved are the costs of the natural gas consumption. The total gas consumption of the building is estimated to be approximately 44100m^3. With an energy content of natural gas of 9.77 kWh/m^3 [93] and a price of 0.08 €/kWh [94], the yearly costs of gas are around €34480 per year. This calculation results in an IRR of 11.04% and a PBP of 10 years, which is again less profitable than the base case.

In the following, the scores for the environmental criteria are determined. First, the potential to save CO_2 will be calculated for the heat pump. For this one, the emissions from a gas boiler are added to the base case, since we are now considering electricity and heating. From natural gas, 0.18 kgCO_2/kWh [95] are emitted, which leads to emissions of 15516 kgCO_2 for one building. Together with the emissions for the electricity, a total of 20585 kgCO_2 are emitted per building for the base case. With the increased self-consumption, about 50% of the electricity is taken from the grid. For the communal consumption of one building this leads to 3621 kgCO_2 and for the additional electricity used by the heat pump, another 6302 kgCO_2 are emitted. Further, the leakage of small amounts of refrigerant from the circuit of the heat pump, has a significant impact on the overall emissions. According to Johnson et al. [96] the refrigerant leakage is responsible for about 10% of the total emissions, since it is a strong GHG, which corresponds in this case to about 700 kgCO_2-equivalent. In total, the emissions per building are then 10623 kgCO_2-equivalent, which is 9962 kgCO_2 less than for the base case. In total, for the whole complex, 49809 kgCO_2 emissions are saved.

Heat pumps are electronic devices that need some rare materials, such as all the electronic devices. Next to this, the heat pumps use a coolant fluid (R410a for the heat pumps that are chosen for this case), however, this fluid is not a rare material. For these reasons, the heat pumps are considered to have a moderate need for rare resources.

Operation of the heat pumps does not produce any waste, however, when the machines are at the end of their lifetime, electronic waste and coolant fluid waste remain. This electronic has a high potential for recycling, which also holds for the coolant fluid, which can be re-used [97].

The heat pump on itself is around 110x210x144 centimeter, which is relatively large. However, this is not a big problem, since heat pumps have to be installed outdoors, for example on the roof of a building. In addition to this, heat pumps require that a circle of one meter around the machine is clear, which is used as a service zone, to make sure that maintenance can be done and the system can operate efficiently. Since heat pumps on large buildings are typically installed on the roof, the installation of heat pumps means that less PV-panels fit on the roof. Due to this reason, heat pumps are indicated to have a very high space requirement.

Many heat pumps are available that are not only able to supply heat, but also supply cooling. This means that heat pumps provide a high increase in comfort for the inhabitants of the apartments.

Heat pumps use electricity to provide heating or cooling to the apartment complex. This electricity can be generated by a PV-system. This means that heat pumps replace an heating system, that, for example, uses natural gas to provide heating. This means that the building no longer is dependent of the natural gas network, but can provide heating them self. Due to this reason, is is assumed that the heat pumps increase the independence.

Heat pumps only need little maintenance. This maintenance will increase their life span and energy efficiency [98]. For this reason, it is concluded that heat pumps need moderate maintenance.

Heat pumps can replace old heating systems, such as natural gas heaters. When this is done, no gas is burnt locally to heat the building, which means that no emissions occur from burning this gas. This means that there will be an improvement in the local air quality by placing heat pumps.

The heat pump is an electronic machine, and there are always risks present when using electronic systems, such a short circuiting or breakdowns. Another important component of the risk, is the coolant fluid that is needed to operate heat pumps. This fluid, named R-410A, is know for the high global warming potential. The global warming potential represents an indicator of the ability to warm up the climate. The global warming potential of R-410A is 2088, which indicates that it is 2088 times more harmful than CO2. This hazard occurs when the heat pump leaks coolant. For this reason, the risks for hazards or accidents for heat pumps is considered to be high.

B.3.6 Home energy management system

The last solution to increase self-consumption is a load management system, that allows to smartly control a number of appliances. An example of such a system is the Smappee home system, that can be installed for around €350, according to the dealership AirTeq, who provided this price upon request. Again, the total investment costs for the whole building complex are calculated, which are €5250 .

The potential to increase self-consumption of such load management solutions depends largely on the number and type of appliances that are controlled by the system. In this case, we are considering, that the washing machine, dryer, and dishwasher are smartly controlled. Widén [99] conducted a study, to assess the increase of self-consumption resulting from the smart control of these appliances, and found an increase of 2% for a system size similar to our case. Again, it is important to note, that this increase is only for the part of the system connected to the apartment using the load management system.

Further, the IRR and PBP for a PV-system project with a load management system in every participating apartment are calculated. An IRR of 13.79% and a PBP of 8 years are found. This means that this solution is again less profitable than the base case.

The environmental criteria for this case are assessed in the following. The amount of CO_2 save by implementing this measure is calculated, like for the other cases, by comparing it with a base case. The base case is the same as for the first two solutions, where the total CO_2 emissions per apartment were calculated to be 792 kgCO_2. With the energy management system the amount of energy taken from the grid can be reduced to 68%. The energy usage of the system itself and the footprint of the production are considered to be negligible. The total emission for this case are then 769 kgCO_2 per year, which is 23 kgCO_2 less than the base case. In total, 339 kgCO_2 can be saved.

The load management is a small electronic device. This device does not contain specific rare metals, except for electronic components that use small amount of rare metals. For this reason, it is decided that the load management system has a low need for rare resources.

As mentioned before, load management systems are small devices with electronic components. The devices produce some electronic waste and some plastic waste, due to which it is decided that the waste production is medium.

The Smappee load management system can consist of multiple modules that can be installed in home. These modules are small, for example 32 x 44.5x 31 millimeter for a specific module [100]. It is concluded that a load management system such as the Smappee system therefore requires very little space.

The load management system yields a small decrease in comfort. It typically decides when devices get electricity, for devices that can vary in energy demand. This means that not all devices work will work optimally at all times, which might reduce the comfort slightly. However, this reduction is very limited when the system is used properly.

The system changes the supply of electricity, and will yield an increase in self consumption of about 2%. This increase is considered neglegible, so it is concluded that this will not change the dependency of other systems.

The Smappee load management systems are small electronic devices which do not need any maintenance. The system can be updated wireless, and problems can be solved digitally. For this reason, the need for maintenance is considered to be very low.

The load management system does not replace a system that pollutes the air, or does not decrease emissions or cleans the air. It is concluded that a load management does not increase the local air quality.

The Smappee load management system is a small electronic device that controls electricity supply en demand. The system does not require a lot of operating power and the risk of accidents is very low, and there are also very little hazards attached to the system.

An overview of all the scores can be seen in Table 26.

Table 26: Summary of scores for every criteria

	Li-ion batt. per ap.	Salt water batt. per ap.	Li-ion batt. (communal)	EV charging stations	central heat pump	Load management	+/-	Unit	Weight
Additional cost of investment	46980	131625	41755	18990	434304	5250	-	€	5%
IRR for whole project	11.45%	4.55%	11.20%	16.44%	10.39%	13.79%	+	€	30%
PBP for whole project	9	17	9	7	10	8	-	years	15%
kg CO2 saved per year	3179.81	4051.52	6714	6015	49809	339.47	+	kgCo2	10%
Need of rare resources	++	+	++	-	-	-	-	/	5%
waste production	++	+	++	0	+	0	-	/	5%
space requirement	-	+	-	+	++	−	-	/	5%
Increased comfort	0	0	0	+	++	-	+	/	5%
Increased independence	++	++	+	++	++	0	+	/	5%
necessity of maintenance	0	0	0	0	+	0	-	/	5%
air quality improvement	0	0	0	1	1	0	+	/	3%
risk of hazards or accidents	0	-	++	+	++	0	-	/	7%

B.4 Results

The scores gathered so far, will be used to create a ranking of the different alternatives. As described in the methodology section of this part, the first step is the calculation of the standardised scores for the quantitative criteria. The result thereof can be seen in Table 27. Next, the quantitative dominance scores are calculated according to the equation 13 mentioned in the methodology section. These dominance scores are presented in Table 28. Then the qualitative dominance scores are calculated according to equation 14, and these can be found in Table 29. Finally, the quantitative and qualitative dominance scores are summed up, and overall dominance score is the result. This can be seen in Table 30.

From the table with the overall dominance score, the ranking of the different solutions can be determined. The salt-water battery has only negative dominance scores, which means that it is less good than any other solution. Therefore it is ranked last. The communal Li-ion battery has one positive score, so it is ranked second to last. The central heat pump comes next with two positive scores, then the the Li-ion battery for a single apartment follows. The load management system is the second best solution and the EV-charging stations are the best solution. The ranking is presented again in Table 31.

Table 27: Standardised data for quantitative criteria

	Li-ion batt. per ap.	Salt water batt. per ap.	Li-ion batt. (communal)	EV charging stations	central heat pump	Load management
Additional cost of investment	0.903	0.705	0.915	0.968	0.000	1.000
IRR for whole project	0.580	0.000	0.559	1.000	0.491	0.777
PBP for whole project	0.800	0.000	0.800	1.000	0.700	0.900
kgCO2 saved per year	0.057	0.075	0.129	0.115	1.000	0.000

Table 28: Quantitative dominance scores

	Li-ion batt. per ap.	Salt water batt. per ap.	Li-ion batt. communal	EV charging stations	central heat pump	Load management
Li-ion batt. per ap.		0.302	-0.001	-0.165	-0.007	-0.073
Salt water batt. per ap.	-0.302		-0.304	-0.467	-0.310	-0.375
Li-ion batt. (communal)	0.001	0.304		-0.163	-0.006	-0.072
EV charging stations	0.165	0.467	0.163		0.157	0.092
central heat pump	0.007	0.310	0.006	-0.157		-0.066
Load management	0.073	0.072	0.072	-0.092	0.066	

Table 29: Qualitative dominance scores

	Li-ion batt. per ap.	Salt water batt. per ap.	Li-ion batt. communal	EV charging stations	central heat pump	Load management
Li-ion batt. per ap.		-0.020	0.050	-0.100	0.020	-0.020
Salt water batt. per ap.	0.020		0.070	-0.010	0.040	0.120
Li-ion batt. (communal)	-0.050	-0.070		-0.150	-0.030	-0.020
EV charging stations	0.100	0.010	0.150		0.070	0.010
central heat pump	-0.020	-0.040	0.030	-0.070		0.010
Load management	0.020	-0.120	0.020	-0.010	-0.010	

Table 30: Overall dominance scores

	Li-ion batt. per ap.	Salt water batt. per ap.	Li-ion batt. communal	EV charging stations	central heat pump	Load management
Li-ion batt. per ap.		0.282	0.049	-0.265	0.013	-0.093
Salt water batt. per ap.	-0.282		-0.234	-0.477	-0.270	-0.255
Li-ion batt. (communal)	-0.049	0.234		-0.313	-0.036	-0.092
EV charging stations	0.265	0.477	0.313		0.227	0.102
central heat pump	-0.013	0.270	0.036	-0.227		-0.056
Load management	0.093	0.255	0.092	-0.102	0.056	

Table 31: Ranking of solutions

Solution	**Ranking**
Electric vehicle charging stations	1
Load management	2
Li-ion Battery (per apartment)	3
Central heat pump	4
Li-ion battery (communal)	5
Salt water battery	6

The result of this MCA need to be treated with caution for several reasons. First of all, many of the values used as input for the numerous calculations, needed to be estimated, because no research fitting our exact case could be found. The high number of estimations made comes with a very high uncertainty of the results.

Further, the project group did not expect, that most of the proposed solutions would turn out to be in in the end not profitable. The question arises if the solutions that fail to meet the primary goal, which was to make solar systems more profitable, should be disregarded. For example, the load management system which is ranked second in the MCA, has favourable scores, because of its low investment costs, good environmental criteria, and because it is very practical, but it isn't financially interesting. This means there would be little to no motivation to make this purchase, in the case that we analysed. And yet the criteria chosen in the beginning lead to a very high score. The same argumentation could be brought forward for the three solutions involving battery storage, which are at the current prices for batteries, not yet profitable. These solution can however increase the independence from the grid or lower the GHG emissions, and might be an option for someone who values those things more, than financial profitability. Similarly, the purchase of a heat pump might not be profitable, but it can still be a valid choice for environmental or comfort reasons.

Since the weights used in this MCA were chosen by the project group and represent the subjective views of it's members, a stakeholder analysis was conducted, to see it the outcome changes based on the importance of the different criteria. One set of weights was provided by the project partner Veldhoven Duurzam representing their focus for this project. The weights can be seen in Table 32, and the ranking resulting from these weight is presented in Table 33. The only difference from the previous ranking is that the central heat pump moved to the last place, because of the high investment costs and the high relative importance of this criteria.

Table 32: Criteria and weights for Veldhoven Duurzam

Category	**Criteria**	**Dimension**	**Weight**	**Sum per category**
Economic	Additional cost of investment	€	20%	**40%**
	IRR for whole project	%	10%	
	PBP for whole project	years	10%	
Environmental	kg CO2 saved per year	kgCO2	10%	**20%**
	Need of rare resources	qualitative	5%	
	waste production	qualitative	5%	
Practical	space requirement	qualitative	5%	**30%**
	Increased comfort	qualitative	5%	
	Increased independence	qualitative	10%	
	necessity of maintenance	qualitative	10%	
health and safety	air quality improvement	qualitative	3%	**10%**
	risk of hazards or accidents	qualitative	7%	

Table 33: Ranking of solutions for weights of Veldhoven Duurzam

Solution	**Ranking**
Electric vehicle charging stations	1
Load management	2
Li-ion battery (per apartment)	3
Li-ion battery (communal)	4
Salt water battery	5
Central heat pump	6

Another set of weights was considered, that should represent the interests of a very environmentally conscious person or environmental organisation. The weights for this case are presented in Table 34, and the ranking can be seen in Table 35. For this case, the only difference from the original case is that the central heat pump moved from fourth to second place.

Table 34: Criteria and weights for focus on environment

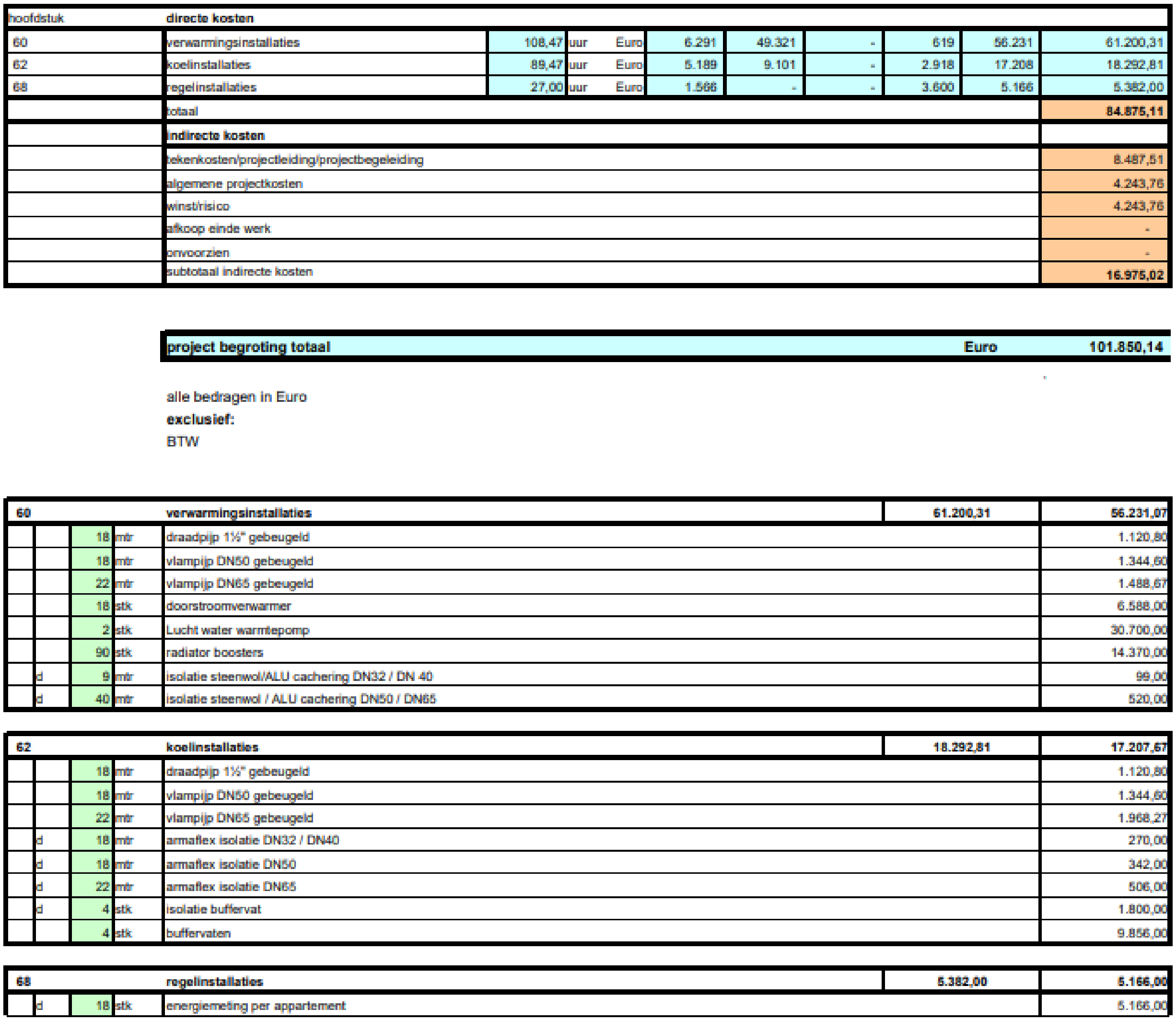
Category	Criteria	Dimension	Weight	Sum per category
Economic	Additional cost of investment	€	5%	**30%**
	IRR for whole project	%	15%	
	PBP for whole project	years	10%	
Environmental	kg CO2 saved per year	kgCO2	15%	**40%**
	Need of rare resources	qualitative	15%	
	waste production	qualitative	10%	
Practical	space requirement	qualitative	5%	**20%**
	Increased comfort	qualitative	5%	
	Increased independence	qualitative	5%	
	necessity of maintenance	qualitative	5%	
health and safety	air quality improvement	qualitative	3%	**10%**
	risk of hazards or accidents	qualitative	7%	

Table 35: Ranking of solutions for weights of Veldhoven Duurzam

Solution	Ranking
Electric vehicle charging stations	1
Central heat pump	2
Load management	3
Li-ion battery (per apartment)	4
Li-ion battery (communal)	5
Salt water battery	6

This stakeholder analysis confirms that the installation of EV charging stations is the best overall solutions for all the stakeholders. The only solutions for which the ranking is ambiguous is the central heat pump. The reason for this is, that it has very large environmental benefits, but also very high investment costs. Here the personal preference plays an important role in the outcome.

C Appendix: Additional information on Heat pump calculation



hoofdstuk	directe kosten									
60	verwarmingsinstallaties	108,47	uur	Euro	6.291	49.321	-	619	56.231	61.200,31
62	koelinstallaties	89,47	uur	Euro	5.189	9.101	-	2.918	17.208	18.292,81
68	regelinstallaties	27,00	uur	Euro	1.566	-	-	3.600	5.166	5.382,00
	totaal									**84.875,11**
	indirecte kosten									
	tekenkosten/projectleiding/projectbegeleiding									8.487,51
	algemene projectkosten									4.243,76
	winst/risico									4.243,76
	afkoop einde werk									-
	onvoorzien									-
	subtotaal indirecte kosten									**16.975,02**

project begroting totaal	**Euro**	**101.850,14**

alle bedragen in Euro
exclusief:
BTW

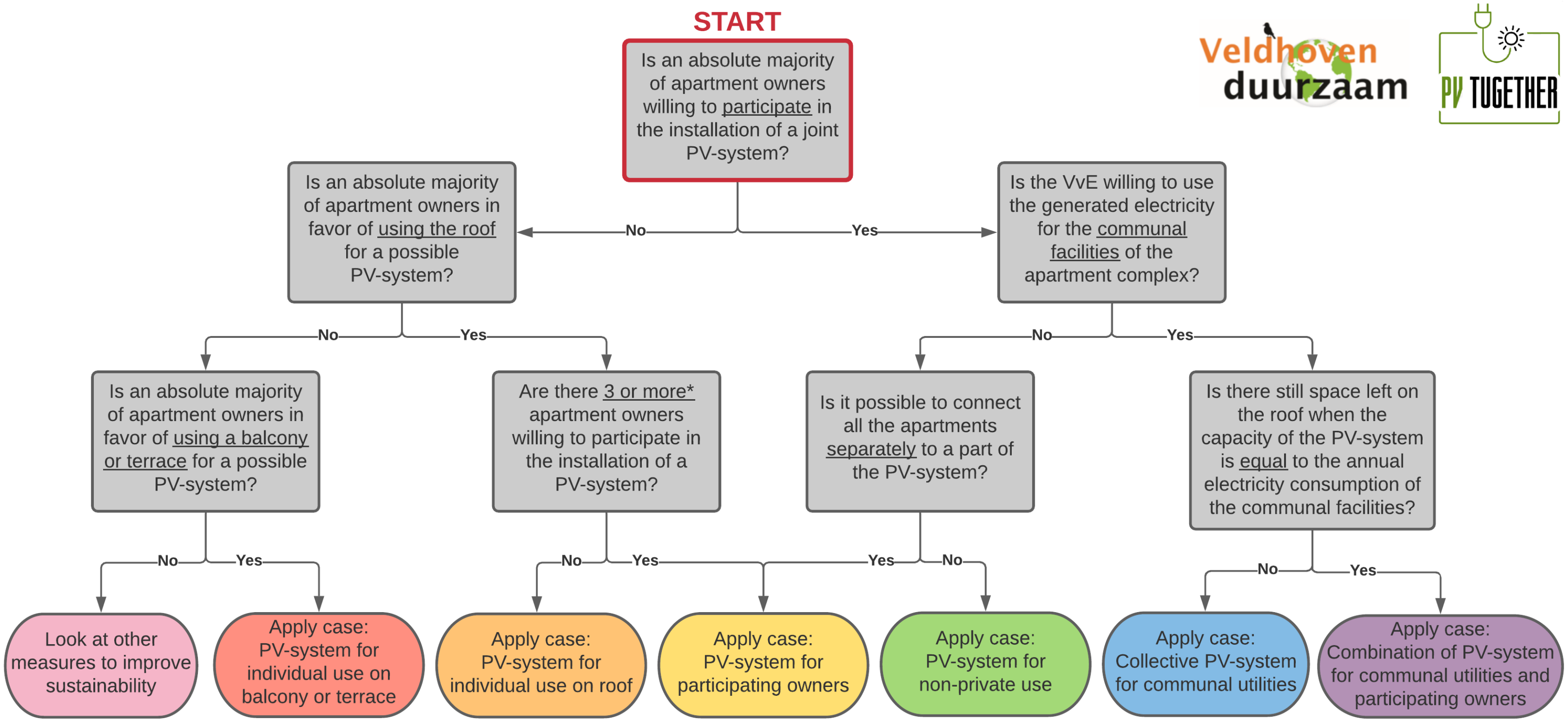
60				**verwarmingsinstallaties**	**61.200,31**	**56.231,07**
		18	mtr	draadpijp 1½" gebeugeld		1.120,80
		18	mtr	vlampijp DN50 gebeugeld		1.344,60
		22	mtr	vlampijp DN65 gebeugeld		1.488,67
		18	stk	doorstroomverwarmer		6.588,00
		2	stk	Lucht water warmtepomp		30.700,00
		90	stk	radiator boosters		14.370,00
	d	9	mtr	isolatie steenwol/ALU cachering DN32 / DN 40		99,00
	d	40	mtr	isolatie steenwol / ALU cachering DN50 / DN65		520,00

62				**koelinstallaties**	**18.292,81**	**17.207,67**
		18	mtr	draadpijp 1½" gebeugeld		1.120,80
		18	mtr	vlampijp DN50 gebeugeld		1.344,60
		22	mtr	vlampijp DN65 gebeugeld		1.968,27
	d	18	mtr	armaflex isolatie DN32 / DN40		270,00
	d	18	mtr	armaflex isolatie DN50		342,00
	d	22	mtr	armaflex isolatie DN65		506,00
	d	4	stk	isolatie buffervat		1.800,00
		4	stk	buffervaten		9.856,00

68				**regelinstallaties**	**5.382,00**	**5.166,00**
	d	18	stk	energiemeting per appartement		5.166,00

Figure 12: Breakdown of the estimation of heat pump cost by Jelle van der Heijden from Nelissen Ingenieursbureau, excluding subsidies.

D Appendix: Road Map



PV-system for individual use on balcony or terrace	PV-system for individual use on roof	PV-system for participating owners	PV-system for non-private use	Collective PV-system for communal utilities	Combination of PV-system for communal utilities and participating owners
The resident purchases a PV-system, which has a direct connection to their own energy meter via the plug and play principle and is installed on their balcony or terrace.	The resident(s) purchases a PV-system, which has a direct connection from the PV-panels on the roof to their own energy meter.	A PV-system is installed as a collaboration between some or all of the apartment owners. The generated solar energy is then distributed to the energy meters of the participating owners. ** 3 or more participants are needed to comply with the requirements of the SCE subsidy regulation.*	The VvE rents out its roof to a third party that in their place will install a PV-system and exploit the generated solar energy. Prices for this can vary and usually third parties set a minimum to the usable roof area.	A collective PV-system is installed and its generated energy is used to power communal facilities such as an elevator or the stairwell lighting.	If there is still space on the roof after meeting the capacity of the communal electricity consumption, interested apartment residents can exploit additional panels for their own electricity consumption. *Note: this option is likely to generate a higher profit, but not necessarily a higher rate of return*

LEGAL STEPS TO BE TAKEN PER PV-SYSTEM CATEGORY

PV-system for individual use on balcony or terrace	• There needs to be a absolute majority of votes (>50%)* in favor of using a balcony or terrace for placing a plug and play PV-system.
PV-system for individual use on roof	• There needs to be a absolute majority of votes (>50%)* in favor of dividing the area of the roof into parts to install a PV-systems • Permission is needed for using the communal fuse box, to place the inverter and install the cables from the PV-system. • Permission is needed for installing the splitters from the communal fuse box to the participating apartments.
Collective PV-system for participating owners	• There needs to be a absolute majority of votes (>50%)* in favor of using the roof to install the PV-systems of participants. • Permission is needed for using the communal fuse box, to place the inverter and install the cables from the PV-system. • Permission is needed for installing the splitters from the communal fuse box to the participating apartments. • After the subdivision is made, the participants of the subdivision can raise a fund, with contribution according to the ownership ratio to cover the cost of the investment, maintenance and insurances.
PV-system for non-private use	• There needs to be a absolute majority of votes (>50%)* in favor of renting out the roof to a third party which will install the PV-system. • Permission is needed for using the communal fuse box, to place the inverter and install the cables from the PV-system.
Collective PV-system for communual utilities	• There needs to be a absolute majority of votes (>50%)* in favor of exploiting the generated electricity from a PV-system for the communal facilities. • Permission for using the communal fuse box is needed, to place the inverter and install the cables from the PV-system. • A fund has to be raised, which will be used to buy the PV-system, to carry out maintenance, to make an insurance contract and to cover other additional costs.
Combination of PV-system for communal utilities and participating owners	• There needs to be a absolute majority of votes (>50%)* in favor of exploiting the generated electricity from a PV-system for the communal facilities. • There needs to be a absolute majority of votes (>50%)* in favor of dividing the remaining area of the roof into parts to install the PV-systems of participants. • Permission for using the communal fuse box is needed, to place the inverter and install the cables from the PV-system. • A fund has to be raised, which will be used to buy the PV-system, to carry out maintenance, to make an insurance contract and to cover other additional costs. • Permission is needed for installing the splitters from the communal fuse box to the participating apartments. • After the subdivision of the remaining roof area is made, the participants of the subdivision can raise a fund, with contribution according to the ownership ratio to cover the cost of the investment, maintenance and insurances.

* Note that a specific VvE regulation can state that there needs to be a certain quorum or other vote amount in favor of it.

Notable subsidies

Subsidieregeling Coöperatieve Energieopwekking (SCE)
Exploitation subsidy consisting of a base amount per kWh produced and a correction amount based on the annual electricity price.
Notable requirements:
- *If not all members of the VvE agree to cooperate, a separate cooperation must be started. All the participants must be living in the 'postcoderoos' at the moment of application.*
- *For VvEs there needs to be at least one contributor per 5 kWp installed power.*
- *For solar panels with a peak power ≥ 15 kWp and ≤ 100 kWp*
- *One can not combine the SCE subsidy with the SDE++ subsidy and other local subsidies are subtracted from the SCE.*
- *There must be a small-scale consumer connection (capacity of max. 3x80 Ampère)*

Stimulering Duurzame Energieproductie (SDE++)
Subsidy based on the amount of electricity produced.
Notable requirements:
- *Peak power of the PV system must be greater than or equal to 15 kWp*
- *There must be a large-scale consumer connection (capacity of min. 3x80 Ampere)*

Investeringssubsidie Duurzame Energie (ISDE)
Subsidy of € 125 per kW combined nominal power
Notable requirements:
- *Annual electricity consumption must be at least 50,000 kWh*
- *There must be a small-scale consumer connection (capacity of max. 3x80 Ampère)*
- *The PV system has a capacity between 15 and 100 kWp*

Apart from the above subsidies, multiple other loans, tax-arrangements and investment deduction arrangements are available. For more information, please refer to "Current opportunities for PV-Systems on apartment buildings in the Netherlands, and solutions to increase self-consumption of solar electricity." by de Clippelaar, van der Heijden, van Meer, Meijvogel, & Slunecko (2021)