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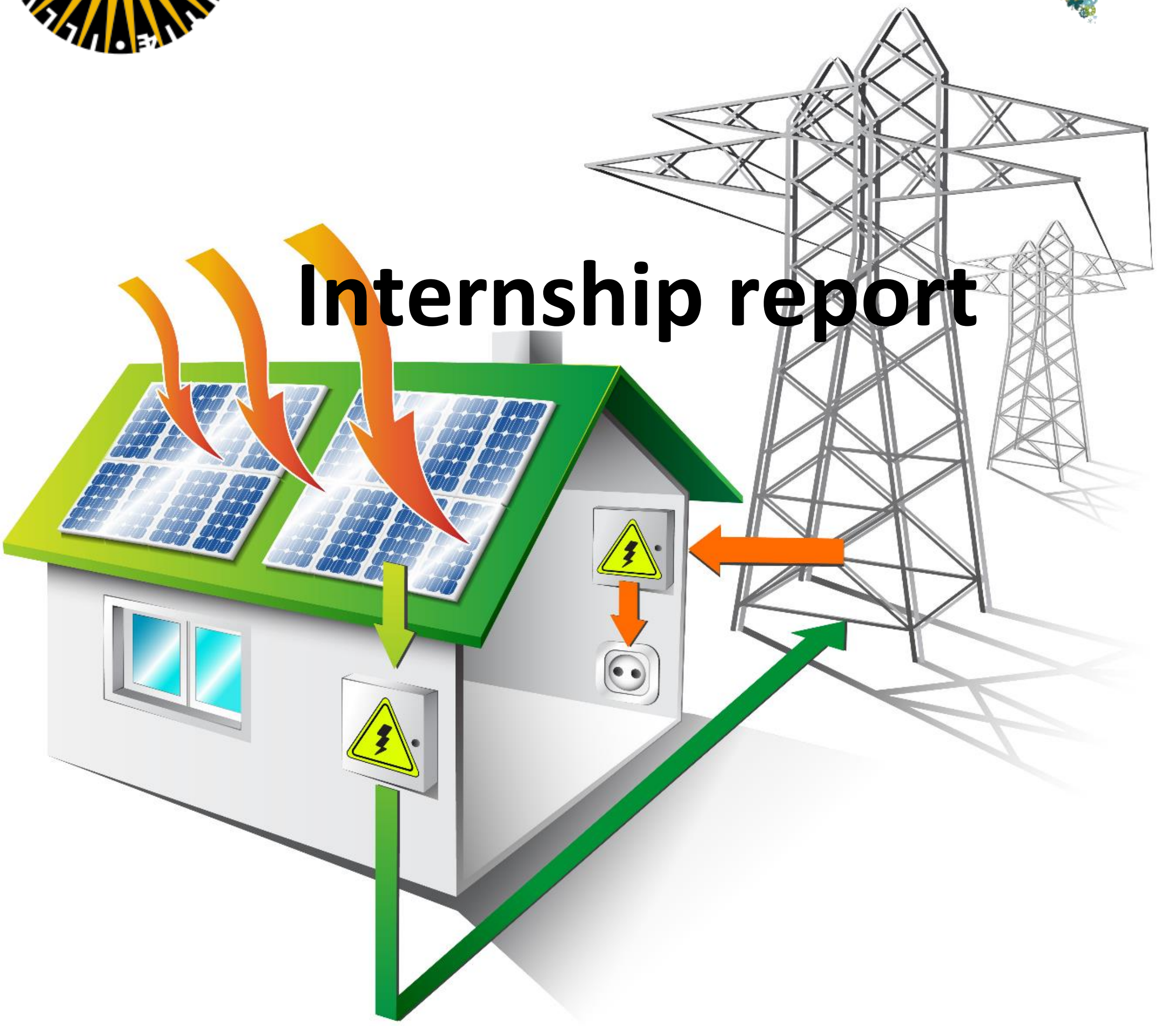

Intended adjustments in net metering: threat or opportunity?

Self-consumption solutions to tackle net metering adjustments for zero net energy residential buildings

Date:	02-07-2015
Name:	M.R. Staats (Maarten)
Supervisor Merosch:	Ing. R. Schilt (Ronald)
Supervisor UU:	Dr. J. Rosales Carreon (Jesus)

Executive summary

A Zero Net Energy (ZNE) building project in RijswijkBuiten has demonstrated that there is a sound business case for this kind of building concept. The concept uses solar panels for electricity generation, which results in a large share of the production being returned to the grid. The net metering regulation increases the value of electricity returned to the grid to the consumer price, which is much higher than the market price. However, the minister of Economic Affairs declared that the current net metering regulation will be reviewed in the coming years for possible adjustments in 2020. This would induce a financial blow to the business case, which could result in ZNE buildings not being (financially) competitive with regular new building projects. It is therefore important to analyze these effects and review possible solutions.

This research has focused on the business case of these kind of buildings after 2020. This was done using data of a small set of ZNE buildings which were built in RijswijkBuiten in 2013. These buildings combined reduced consumption by extensive isolation, airtightness and heat recovery with production of energy with solar panels and heat pumps. In an average year these buildings should produce about 3300 kWh, directly consume 650 kWh and net meter 2650 kWh.

The first part of the research (section 5) focused on financial implications of adjustments of net metering regulation. Therefore, an analysis of price trends of electricity and equipment was done towards 2020. This resulted in two scenarios for the electricity price, a 'low' scenario with 1% increase and a 'high' scenario with 3% increase. Cost figures for the energy related equipment (solar panels and heat pumps) were extrapolated from previous years towards 2020, which resulted in an estimated total cost reduction of €3525 by 2020. Next, possible net metering adjustment scenarios were constructed based on interviews and formal papers and transcripts. The two constructed adjustment scenarios in this research were total abolishment of the regulation, where electricity returned to the grid is only remunerated with the wholesale market price, and a fixed tax reduction on top of the market price of €0,075/kWh for the coming years.

Thus, a total of four scenarios were used: a low price increase with total abolishment, a high price increase with total abolishment, a low price increase with a fixed tax reduction and a high price increase with a fixed tax reduction. The NPV breakdown of electricity returned to the grid with net metering and with adjustments to net metering is displayed in figure S.1

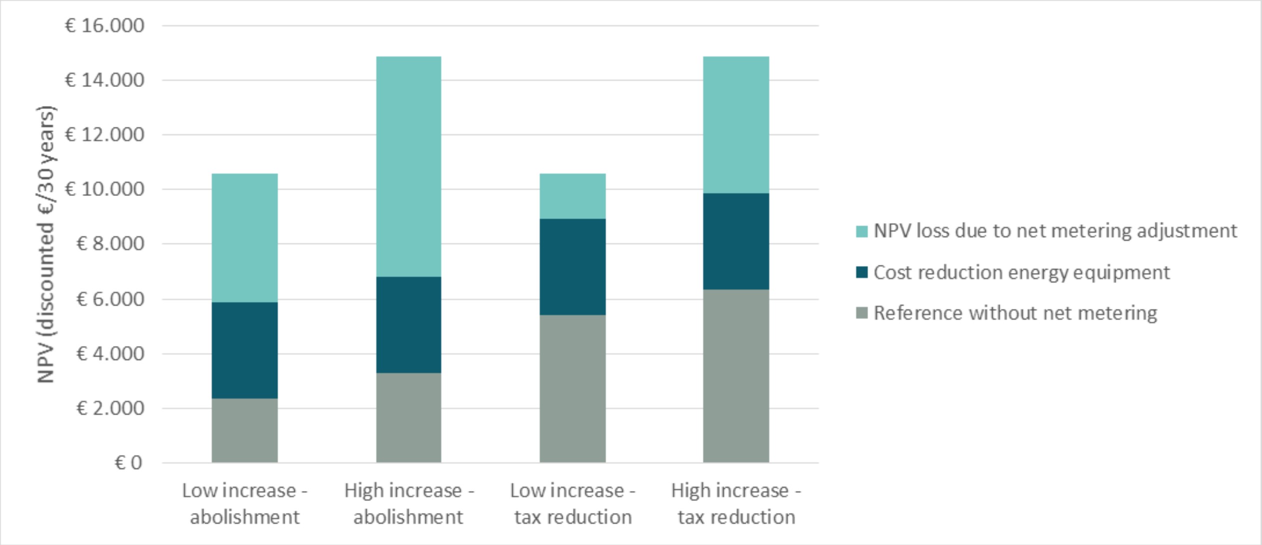

Figure S.1: NPV breakdown of effect of adjustment in net metering
The whole bar illustrates the NPV of electricity under current net metering regulation.
The grey section shows the NPV of electricity under adjusted net metering regulation
The dark blue section shows the NPV improvement due to cost reduction.
The light blue section shows the remaining loss of NPV due to net metering adjustments.

Without any changes to the concept, this would result in a NPV gap for the concept of between €5.177 (low price + tax reduction) to €11.570 (high price + abolishment). The cost reduction of energy related equipment reduces this gap to between €1.652 and €8.045. The gap is considerably lower due to the cost reduction, but still has a significant effect on the business case of this ZNE-concept.

The second part of this research (section 6) focused on technological solutions to reduce this gap. Three possible technological solutions were reviewed to confront this NPV gap. These were electricity storage, Demand Side Management (DSM) and differentiating the solar panel orientation. The best storage solution for this case would be a lithium-ion battery. The storage potential of different battery sizes were calculated to find the financially optimal size. The optimum size was between 3,5 and 5,5 kWh (depending on the scenario), while a battery could reduce the NPV gap of the low price + tax reduction scenario with only €89, while in the other scenarios it could reduce the gap with between €1.585 and €3.385.

The DSM option reschedules the production of hot water from the late evening to the afternoon. Doing this 'dumb' by setting it to a preset fixed time could reduce the amount of kWh returned to the grid with 265 kWh (which is 10% of total) and does not require investment costs. The decrease of the NPV gap due to 'dumb' DSM would be between €518 and €1.157 (depending on specific scenario). Alternatively the same principle can be applied 'smart' by starting the hot water production based on solar electricity overproduction. This could generate an extra increase of between €96 and €214. However, this does not include the extra investment costs for hard and software as well as system tuning. The relative small increase of the 'smart' option does likely not justify the extra expenditures in investment costs, which renders the 'dumb' option as better solution.

The last technological solution reviewed is a change in orientation of solar panels. The current orientation which is south-east by south with 38 degree inclination could be adjusted to change the production profile to better match the demand pattern. Three new orientations were analyzed on their increase in self-consumption: southwest orientation with 38 degree inclination and two half east half west orientations with 10 and 30 degree inclination respectively. The east/west options have a relative large production loss compared to the increase in self-consumption and are therefore not good options for the business case. The southwest option gives 114 kWh more self-consumption while only reducing production with 45 kWh. The NPV increase due this option would be between €131 and €442. This is relatively small compared to the other two options, while it greatly restricts the district planning as all houses are forced to have their tilted roof towards the southwest. It is concluded that the NPV improvement of this option does not justify this limitation and therefore this option is not taken further into account.

The best strategy for this ZNE building concept would be to include a battery and apply 'dumb' DSM with the hot water production. Applying DSM changes the demand profile and thereby reduces the storage potential to some extent. Only in the low increase + fixed tax reduction scenario, storage is barely profitable due to the interaction effects of these two solutions. The original gaps which included cost reduction were between €1.652 and €8.045. These gaps can be reduced to between €1.102 and €4.005 if storage and DSM are included in 2020, as shown in table S.1.

Table S.1: NPV loss due to net metering adjustments when applying both DSM and storage.

Result	Low increase - abolishment	High increase - abolishment	Low increase - tax reduction	High increase - tax reduction
NPV loss due to net metering adjustment	€ 2.425	€ 4.005	€ 1.102	€ 2.896

An overview of the cost breakdown is displayed in figure S.2, where the values of table S.1 are shown in light blue.

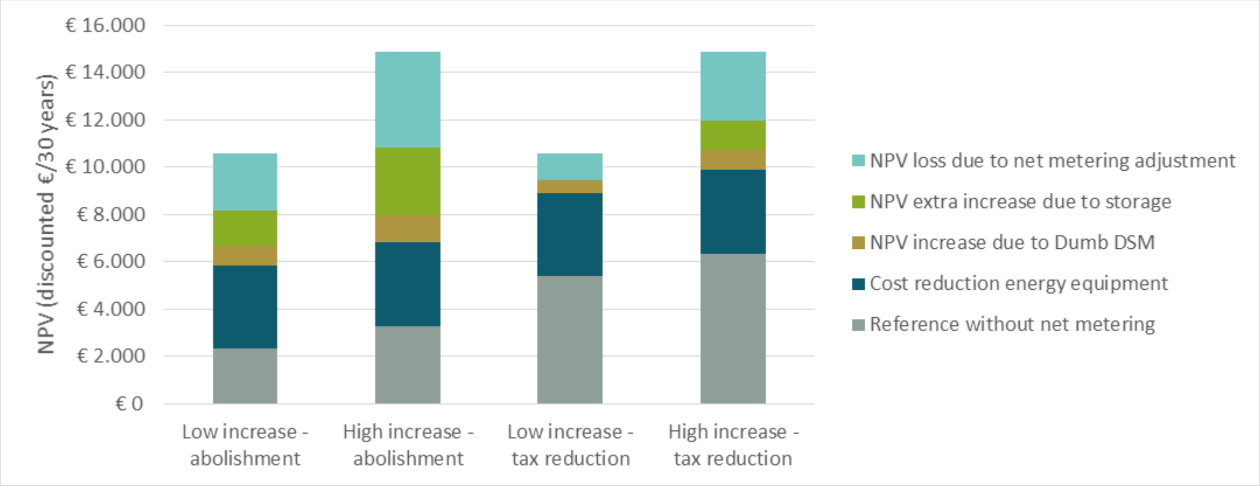

Figure S.2: NPV breakdown of adjustments in net metering including DSM and storage
Breakdown is similar to figure S.1, while NPV improvements of storage (green) and DSM (brown) are added.

This NPV gap is considerably lower than without the solutions, but a significant gap remains. The business case for this ZNE-concept will be worse off even with the technological solutions. Either more cost reductions should be obtained or the government should adjust the net metering regulation later or more limited to keep this concept competitive with regular buildings.

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1. Introduction

The last decades climate change and the depletion of some fossil resources have had increasing attention from supra national, national and local institutions. The European Commission has looked into these issues on a supra national level. In 2010 the European Commission proposed a 10-year strategy to reach agreed targets for development of the European Union. The targets for energy have been the following: 20% of energy from renewable sources and 20% increase in energy efficiency (European Commission, 2015). These supra national targets have been translated to the national level by the Dutch government. The targets the Dutch government imposed on itself are 14% of energy from renewable sources in 2020 and 1.5% increase in energy efficiency per year (Rijksoverheid, 2015). In 2012, 4,5% of energy consumption came from renewable sources, while the energy efficiency increased with 1.1% per year. This indicates that the government has to step up to reach their 2020 targets.

Through policy applied in different sectors the government tries to achieve their national targets. One of these sectors is the residential sector, where one of the most important policies is the restriction on energy use of newly built houses. The government regulates energy use of these houses with the EPC regulation (*Energie Prestatie Coefficient*). The EPC standard is an indication of the relative energy use of newly built buildings compared to the average use of newly built buildings in 1990. The current EPC standard is 0,4, which indicates that construction of new homes can only use 40% of the average use of similar new buildings In 1990. The EPC standard only applies to building-related energy requirements, such as space heating, cooling and domestic hot water. The use of appliances is not part of the EPC standard. The Dutch government have set the target that all newly built homes have to be EPC = 0 in 2020.

On the local level, housing corporations and construction companies are designing and building early projects which confirm to the EPC =0 standard. This is often done by extensive insulation and by applying solar panels. Buildings where all building-related energy is annually produced by dedicated energy sources within a radius of 10 kilometer are called Energy Neutral (EN) (RVO, 2013). A building which is EPC = 0 confirms to the definition of a EN building. However, for a household to be really ‘neutral’ on their energy use, the inhabitants specific use should also be accounted for. This energy use is caused by the use of appliances and lighting. Building concepts which provide enough energy production (often by installing more solar panels) to cover all the energy demand of a household over a year are called Zero Net Energy (ZNE) buildings. Currently there are ZNE buildings being built which almost provide the same costs of ownerships as regular new houses with an EPC of 0.4.

The diffusion of EN- and ZNE- buildings is expected to increase due to the strict EPC = 0 regulation in 2020. During the next five years the business case for EN- and ZNE-buildings has to be reviewed for possible changes in costs and regulation. Exogenous changes such as fluctuations in energy prices and intended adjustments in government policy which exempts household solar electricity from energy tax (called net metering) could have large impacts on the business case. High energy prices will provide for a better business case, as local production will become more profitable, while the abolishment of net metering will cause the electricity returned to the grid to reduce in value, causing a negative effect on the business case. Reduction in costs for building, solar panels or heat pumps could strengthen the business case. All these exogenous effects cannot be controlled by stakeholders on the local level (construction companies, installation companies, housing corporations). Stakeholders can change the building concept to confront these exogenous changes. The effects of net metering adjustments could be tackled by changing the building concept to increase solar electricity self-consumption. This could be done by Demand Side Management (DSM), east-west orientation of panels or applying storage. These ‘endogenous’ changes (changes which can be made by partners around the building project) should be reviewed on their capability to increase PV self-consumption and their potential profitability if the net metering is adjusted. Studying both the exogenous and endogenous changes could provide for valuable information on the forthcoming changes in the building sector and possible ways to provide guidance to these changes for both governments, market parties and other institutions.

2. Problem definition and research question

The most immediate threat to the business case of EN- and ZNE-buildings is the expected change in net metering regulation (Dutch: *salderingsregeling*). This policy defines that excess solar electricity can be delivered to the grid and the same amount may be taken from the grid without extra charge (Rijksoverheid, 2014). Without the net metering regulation, households would currently buy their electricity for around €0.22/kWh but can only sell their excess electricity to the grid for the market price of around €0.05/kWh. Especially for ZNE-buildings with a large amount of solar panels (and thus a high amount of electricity returned to the grid), this would indicate a considerable yearly expense.

An example of such a ZNE-building can be found in RijswijkBuiten. There are five newly built ZNE homes in this suburb close to the city of The Hague, together with 200 EN buildings. They have been built with extensive insulation, heat pumps and a large array of solar panels. The project is built with guarantees that the solar panels will produce an equal amount of electricity as the whole house consumes over a period of one year. The households are provided with very energy efficient household appliances and LED lighting. The additional costs for these households are currently €20.000 euro, but this reimburses itself by reducing the energy costs to zero. Alternatively the home-owners lease the equipment and pay a monthly fee similarly to the energy costs of a comparable home. This concept therefore currently shows the same costs of ownership as a normal newly built house. Adjustments in net metering could possibly induce tens of thousands of euros extra electricity costs for the inhabitants due to the price gap between electricity returned to the grid and electricity taken from the grid. This will result in a blow to this kind of building concept, leaving this concept much more expensive than a 'normal' house with an EPC of 0,4. However, the configuration of efficient electric heating and cooling with a heat pump requires a relative low amount of solar panels. Therefore, the problems which arise due to net metering adjustment will be higher for concepts which are using even more solar panels.

It is therefore very important to identify the extent of the financial effects of adjustments in the net metering regulations. Most importantly, the most likely scenarios for net metering adjustment have to be considered, as these directly influence the induced electricity costs for ZNE-building owners. Another important parameter which influence this financial 'blow' is the price developments of solar panels and heat pumps, as these are key differences between a ZNE-building and a EPC 0,4 building. The change in energy prices does also effect the 'loss' due to net metering adjustments. All these changes should be reviewed to analyze the effect on the business case and to obtain a guideline for further development.

To confront the possible changes in net metering some endogenous adjustments can be made in the business case to increase solar electricity self-consumption. An adjustment which would significantly reduce the amount of kWh returned to the grid would result in a much more resilient business case, as the effects of changes in net metering will be reduced. One of the easiest ways to do this is to install a storage device, which can charge during excess solar production and discharge during periods without solar production, reducing the amount of excess solar electricity returned to the grid. There are a large variety of storage technologies available, which should be reviewed and the most appropriate ones for small scale storage in residential areas should be selected, after which the potential for increase in solar electricity self-consumption should be calculated.

However, other methods could be applicable too. For example changing the orientation of the panels from south to more west or east will result in less total production, but the production is more evenly spread over the solar hours. Demand Side Management (DSM), changing demand from hours without solar to hours with high solar production, could also result in more self-consumption of solar electricity and less electricity returned to the grid. While the potential for self-increase of these options is likely to be relatively low compared to storage, their benefit of a limited investment requirements make them important to take into account. All options to increase solar electricity self-consumption will be taken into account, but the main focus will be on storage due to the high self-increase potential.

The effects of exogenous and endogenous changes on ZNE buildings will be reviewed based on data from a ZNE-building project in RijswijkBuiten. This is done using the following main research question:

“What will be the financial effects of adjustment in net metering regulation for ZNE houses in 2020 and to what extent can technological solutions confront these effects?”

This is done using the following sub questions:

1. What are the trends in prices for electricity and energy related equipment?
2. What is the effect of likely scenarios of adjustments in net metering on the business case of ZNE building projects?
3. To what extent can technological solutions help to improve the business case for ZNE-buildings?
4. What are the financial gains of applying the technological solutions?

3. Background information

This research requires some background information on the topic which are analyzed. This section will provide a description of the analyzed houses and the breakdown of the energy related equipment and electricity price. It will also clarify the current net metering regulation and how the technological solutions will ensure a lower amount of electricity returned to the grid.

3.1 ZNE-concept in RijswijkBuiten

The ZNE-buildings analyzed within this research are townhouses within the municipality of Rijswijk. The buildings are inhabited since 2013 and consists of a serried set of five townhouse. The ZNE-buildings have extensive insulation and are tested for airtightness. The heating of the house is done by a heat pump of 3,5 kW (thermal). The households are provided with vouchers to buy A+++ household appliances, as well as a voucher for LED lighting and standby killers. This demand is provided by 15 or 16 solar panels on the roofs of each house summing up to a rated power production of 3,9 kWp. The production of these panels will be around 3300 kWh per year on average. From this 3300 kWh, there is a direct use of 650 kWh throughout the year, while the remaining 2650 kWh is returned to the grid, to be used at a later time. This indicates that currently from the production about 20% is directly used by the household, while the remaining 80% is returned to the grid.

3.2 Price breakdown of energy related equipment

The solar panels and heat pumps applied within the ZNE-buildings are priced based on a set of components of materials and labor. The price of solar panels are based on the cost of the modules itself, the required AC/DC inverters, installation costs and taxes. Sometimes there are also extra adjustments in the house required, such as investments in an electricity group or frame. Some overviews of price developments for solar panels only include the module price itself, while other present a so called ‘turn-key’ price, which include all costs for the panels, inverters and installation. The ‘turn-key’ price is a more suitable indicator, as the module price only shows a part of the total price of a solar panel system. Therefore, the ‘turn-key’ price is used within this research.

The price for heat pumps also depends on different components, such as the heat pump itself, the drilling of a source, storage tank and installation. Equivalent to the solar panels, there are sometimes cost projections for the heat pump itself, not taking into account the other components of the total cost. This research will therefore focus on a ‘turn-key’ price indicator, which includes all price components (without tax).

3.3 Electricity price

The electricity price which is paid by consumers consists of a set of components which built up the total price. The components are:

- The market price: the price for which electricity is bought and sold on the wholesale market
- The suppliers premium: the premium required by the supplier over the market price.
- Energy tax: the tax the government levies over electricity use to increase the price and thereby
- Value Added Tax (VAT)

The breakdown of the components are displayed in figure 1.

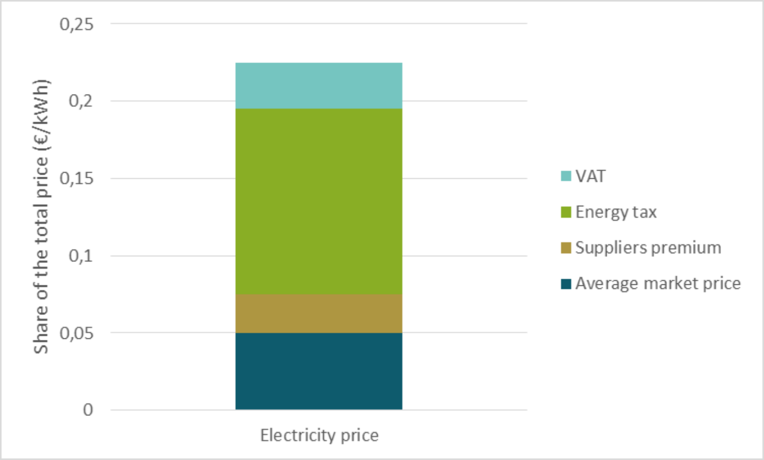

Figure 1: Breakdown of electricity price for consumers (Milieucentraal, 2015).

3.4 Net metering regulation

The breakdown in figure 1 indicates that a large share of the electricity price is made up by taxes. This indicates that selling electricity on the market price is much less profitable than reducing the consumption of electricity from the grid, as the ‘profits’ from the latter include the taxes. The current net metering regulation is based on this principle. Households with solar panels tend to return a large share of their production back to the grid (especially in the summer in the middle of the day) and take a large share of their total consumption from the grid (especially at night). The net metering regulation provides for the possibility to cancel out the electricity returned to the grid to the electricity taken from the grid. This results in the households not selling their overproduced electricity against market price, but reducing the amount of kWh of electricity taken from the grid which has to be paid for by the households. This effectively means that currently the electricity returned to the grid is valued at the consumer price. The net metering regulation is currently not limited to a certain amount of kWh net metered per year. It is only limited by the yearly use of the house which contains the solar panels. If there is more electricity produced in one year than the consumption of the affiliated household, the returned electricity is valued at the market price or the market price plus suppliers premium. Until 2014 the total amount of electricity which could be net metered was 5000 kWh.

There are three main objections against the current net metering regulation. The mostly used one is that the net metering regulation results in the elimination of any incentive for households to increase their self-consumption. Under the net metering regulation electricity returned to the grid has the same value of electricity which is directly self-consumed. Households are not encouraged to decrease their ‘burden’ on the grid. The second argument is that the regulation let households unfairly use the grid as storage medium. The electricity which is consumed outside of solar hours is produced by other electricity providers and is not in any way related to the electricity returned to the grid in solar hours. The net is not built for large differences in consumption and (local) production, but the grid has to balance their overproduction and consumption at all time. The last argument is that net metering regulation has large impacts on the government finances. Households with a large amount of solar panels reduce the amount of taxes they pay for their electricity largely. This results in less government revenue, while subsidies and tax reductions on solar panel purchase and installation have imposed significant costs on the government. This last argument is controversial as it implies that the government has a ‘right’ to revenues on energy use. But if the households produces this energy himself, it is justifiable to exempt them from this tax. In addition, adjustments in net metering will result in incentives to increase the self-consumption of the household and will therefore also result in less energy tax paid.

3.5 Technological solutions

The technological solutions discussed in this research are electricity storage, Demand Side Management and differentiating solar panel orientation.

3.5.1 Technological solution 1: Storage

Storage can increase self-consumption by storing excess electricity production in a storage device. This can be done for example by electro-chemical energy conversion or by conversion of electricity to gravitational energy. The overproduced electricity can be used by the household at a later time instead of taking electricity from the grid, which increases the self-consumption of the household. The most important aspects of storage medium to increase self-consumption are:

- Size: the storage medium should be able to store a decent amount of electricity (several kWh’s)
- Price: If the price of storage is too high, the costs cannot be recovered within the lifetime of the project.
- Lifetime: The longer the storage medium lasts, the longer the household can benefit the profits of storing electricity compared to returning it to the grid.
- Efficiency: a low efficiency results in much less electricity self-consumed due to losses in the storage process.

3.5.2 Technological solution 2: Demand Side Management

Demand Side Management (DSM) is the change of demand to meet the production of renewable energy. This can be done by rescheduling appliances from hours without solar electricity production to hours with excess solar electricity production. For example, if the dishwasher is not started just before inhabitants go to bed but in the afternoon, there is more direct use of the solar generated electricity. Not all appliances are practicable for DSM, as for most appliances the usage time is not easily adjustable. Energy use in cooking is generally around dinner time, ICT equipment is used when the inhabitants need their services and lighting is used when there is not enough sunlight. All these kinds of demand can thus not be adjusted to hours with more solar electricity production. Other appliances are easier to adjust in time, but do not have a significant effect on the energy use of households: for example cellphone chargers. Within ZNE-buildings such as in RijswijkBuiten there are generally two types of appliances which provide for a significant demand and are relatively easy to change in time:

- Wet appliances: the wet appliances include the washing machine, tumble dryer and dishwasher. A study from DNV GL and Utrecht University found that there is a significant potential for increase in self-consumption for especially dishwashers, while the washing machine and tumble dryers are often already used during solar hours. However, to achieve this potential either the inhabitants should manually turn on the appliances in the afternoon or specific soft and hardware should be bought and installed. The study argues that the increase in self-consumption does not justify the behavioral chance or investments for the households.
- Heat pump: The heat pump provides heating for the rooms as well as hot water production. The heating of the rooms is in ZNE-buildings only applicable in the winter months which are also the months with the lowest overproduction of solar electricity. Room heating is therefore not very interesting as DSM option. The hot water production is necessary throughout the whole year and is currently started at the end of the evening. This water can also be produced a couple of hours earlier and therefore could provide for a very interesting DSM option.

3.5.3 Technological solution 3: Differentiated solar panel orientation

Solar panels are currently mainly oriented towards the south, as it provides for the highest production throughout the year. This production peaks right in the middle of the day, as the panels are oriented on the position of the sun in the middle of the day. There is a possibility to orient the panels more towards the west or south, which results in the panels being oriented on the position of the sun on a different time and therefore a different peak production time during the day. On the one hand does this reduce the amount of generated electricity over the year, but as demand is usually higher in the morning and late afternoon/early evening this can result in more self-consumption of the produced electricity.

Changing the orientation of solar panels requires the building process to take into account that the roof should be tilted towards the ‘improved’ orientation. This means that a specific requirement on the orientation of the homes greatly restricts how the district is designed. This can only be justified if there is a significant increase in self-consumption. It is also important to take into account that more east or west oriented panels result in a loss in production, which is also a financial loss. To make up for the loss in production and the restrictions to the building process, it is important to have a significant increase in self-consumption to justify this technological solution. This problem does not arise with flat roofs, as the solar panels can be oriented towards the improved orientation, without having impact on the orientation of the house itself.

4. Methods

The research consists of two parts: first a financial analysis will be done to obtain the price trends of electricity and energy related equipment as well as the financial effects of adjustments in the net metering regulation. Then, possible technological solutions for this financial effect will be reviewed. The outline of the research is shown in figure 2.

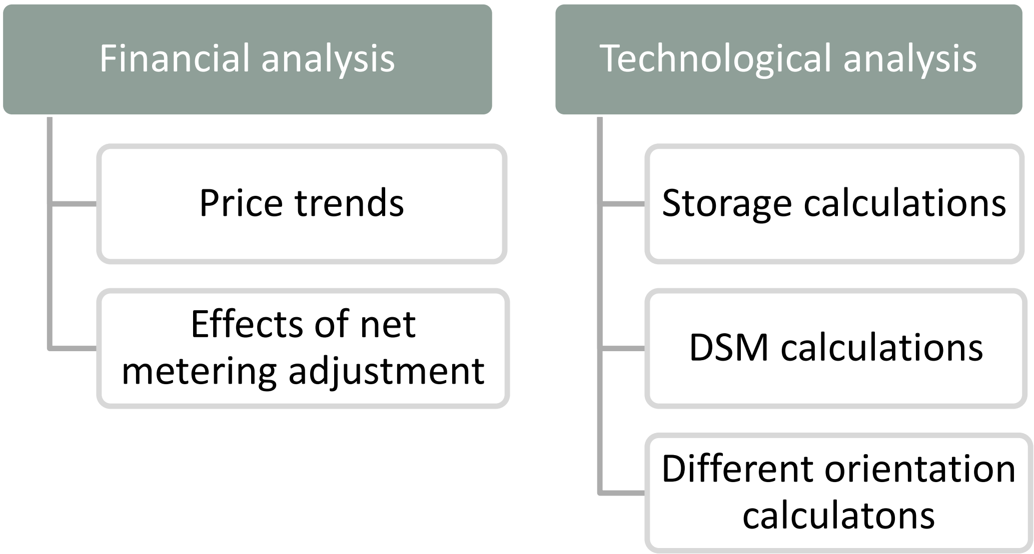

Figure 2: Outline of the research

4.1 Methods for financial analysis

The methods for the financial analysis consists of an analysis of the price trends of electricity, solar panels and heat pumps and of an analysis of possible net metering adjustment scenarios.

4.1.1 Future price estimations

As discussed in the background, there are different prices related to the energy related equipment and energy usage profiles which influence the business case of ZNE buildings. As the net metering regulation will likely be adjusted in 2020, it is necessary to forecast these prices to fit the prices of 2020 and beyond. This research will therefore estimate prices for different variables in 2020 and beyond. This will be done for the following prices:

- Solar panel prices
- Heat pump prices
- Electricity market prices
- Energy tax prices

For all these prices data from previous years will be gathered from scientific literature, reports from governmental- and sector organizations as well as research institutions. These sources are for example the Dutch statistical Bureau (CBS), the Dutch government, the International Energy Agency (IEA), the Dutch Energy Research Organization (ECN) and the Netherlands Environmental Assessment Agency (PBL). To complement market price data of solar panels and heat pumps, data from different suppliers will be taken into account as well. The estimations are based on three different kinds of sources:

- Usual market assumptions: assumptions as currently used by Merosch to calculate business cases with future revenue streams (e.g. average electricity price increase of 3%/year)

- Price/trend assumptions of research institutes (e.g. estimations from CBS, IEA or ECN)
- Extrapolations based on price trends of the last 5 years (e.g. PV module prices of last 5 years)

Usual market assumptions and assumptions of research institutes will be taken into account when generating forecasts, to make sure the assumptions of this report do not vary significantly from assumptions made by experts in this field. Based on these expert forecasts and on price data of the past years, an estimation will be made for the coming years by fitting the previous data with a best fitting trend line. The best fitting trend line is here defined based on the R^2-value, which is a statistical value between 0 and 1 which indicates how well the data points fit the mathematical trend line (Bryman, 2012). The higher the R^2-value, the 'better' the trend line fits with the data points. Trend lines and R^2-values are generated using Microsoft Excel. Trend lines which will be taken into account and the general mathematical equations of these lines are displayed in table 2.

Table 2: Considered trend lines, descriptions and mathematical equation

Trend line	Trend description	Mathematical equation
Linear trend line	Linear growth/decline speed	$€_{\text{year y}} = \text{coefficient} * \text{year y} + €_{\text{base year}}$
Exponential trend line	Increasing growth/decline speed	$€_{\text{year y}} = \text{coefficient} * e^{\text{coefficient} * \text{year y}}$
Logarithmic trend line	Decreasing growth/decline speed	$€_{\text{year y}} = \text{coefficient} * \ln(\text{year y}) + €_{\text{base year}}$

This best fitting trend line will be extended to 2020 or beyond 2020 if necessary and data points for the estimations will be extracted from the trend line.

4.1.2 Net metering scenario generation

The current net metering regulation is likely to be adapted in the near future, as minister Kamp already mentioned that it will be reviewed in 2020. However, it is unclear whether Kamp will still be minister of Economic Affairs in 2020 as next elections will be held in 2017. If the net metering regulation will change and how it will be changing will therefore be the outcome of a political process which cannot be forecasted. However, these changes can have a major effect on the business case of ZNE buildings and it is therefore important to obtain the most likely scenarios in which the net metering regulations will change. This will be done by interviewing experts on this topic which are working with politicians and civil servants on this topic. Next to these experts interviews some background reports have been used to further develop insight into the current regulation and expected future adjustments. The expert interviews and supporting documents can be found in table 1.

Table 1: Sources used for generating net metering regulation

Source	Stakeholder	Type of source
Project manager Energiesprong	Governmental agency	Formal interview
Consultant renewable policy	Advisory firm	Formal interview
Project manager Stedin	Distribution System operator	Formal interview
Project manager Economic affairs	Ministry of Economic Affairs	Informal discussion
Graduation thesis on Net metering	Diverse inputs	Graduation thesis
White paper Energiesprong	Governmental agency	White paper
Presentation ECN	Energy Research Center	Presentation
Several reports on legislative consultation on Net metering	Government/members of parliament	Transcripts of parliament

The actors will be questioned on the current view on net metering and the most likely adjustments in this regulation after 2020. The supporting documents will be reviewed on the statements made on net metering by politicians in charge and civil servants as well as expressed expectations on net metering regulation adjustments. These sources will be combined to form a small set of adjustment scenarios which will be compared to a scenario in which no adjustments are made to the current net metering regulation.

4.2 Methods for technological analysis

The technical analysis of this research focuses on three parts: storage calculations, demand side management calculations and solar panel orientation calculations. The methods for these three parts are separately discussed. Data acquisition was done to obtain data for the three different parts, as shown in figure 3.

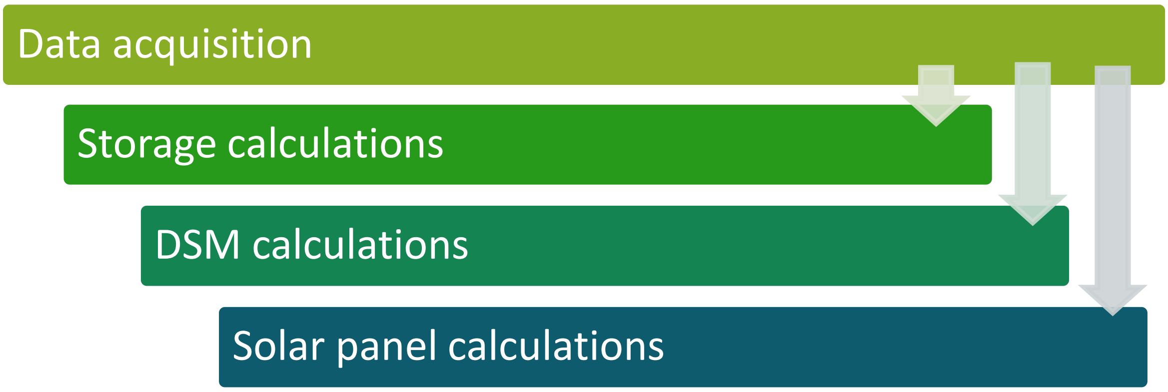

Figure 3: Outline of methods for technological section.

4.2.1 Data acquisition

To analyze the effect of technical options on the business case of ZNE-buildings, data was used which was provided by TNO. The data available at TNO contains electricity measurements of two ZNE-buildings in RijswijkBuiten. The measurements were done from July 2014 to the end of April 2015, containing both the amount of electricity taken from the grid and the amount of electricity delivered to the grid in 15-minute time intervals. To analyze the effects for one year, this data was supplemented to extend to a full year. This has been done in a way to best reflect the overproduction profiles of the missing months of May and June, as this research tried to reduce this overproduction. The solar power production is directly correlated to solar irradiance. Therefore, data for May and June was based on months with similar solar irradiance. Irradiance data from a database of the European Commission shows that July has the closest solar irradiance to May and June. Therefore, data from July was used to fill in the data gap of these two months.

4.2.2 Storage calculations

To find the optimal storage size for ZNE-buildings in RijswijkBuiten it is important to review the most applicable storage technology for small scale residential storage. This was done by reviewing reports from renowned institutions (such as DNV Kema and Ecofys) on applications and characteristics of different types of storage technologies. This was complemented by information from a storage database from the TU Delft. From these sources, the most applicable storage medium was selected. These sources also provide characteristics of these technologies which were used in this research, such as price, round-trip efficiency and lifetime.

However, these sources provide a range in these characteristics, due to differences between specific configuration of the storage. This research required specific data as input to compute the results. Therefore, the technical characteristics of a state of the art storage device were used as example to compute the storage potential in this research. However, the price of this state of the art storage device is currently relatively high, as it is new and price reduction is likely to follow in the coming years. Therefore, the price used in this research was based on recent estimates in scientific literature and from market parties to estimate the battery price in 2020.

The storage capacity of different storage sizes is calculated using a storage algorithm, which can be found in Appendix A. It is important to note that the total stored electricity is not equivalent to the reduction in electricity delivered to the grid in the reference situation. Because when storing electricity, a percentage is lost due to the storage process. For example, if 1000 kWh electricity is not returned to the grid due to a storage appliance with an efficiency of 90%, only 900 kWh is actually available for later use, resulting in 100 kWh electricity loss (which is transformed into heat). So in this scenario total amount of electricity stored would show 900 kWh.

Based on the algorithm the total amount of electricity stored per year was calculated for different storage sizes between 0,5 and 20 kWh. The total overproduced electricity E_t can then be subdivided into three components: the electricity stored and later self-consumed E_s, the electricity lost in the storage process E_l, and the electricity returned to the grid E_r (Equation 1). When there is no storage, E_s and E_l become zero and the total overproduced electricity equals the amount of electricity returned to the grid.

$$E_t = E_s + E_l + E_r \tag{1}$$

4.2.3 Net present value calculations for storage

To calculate the (possible) financial gains of applying storage in a ZNE-building the Net Present Value (NPV) was calculated. The NPV gives the current value of future cash flows. The investments costs and yearly benefits and costs are discounted to obtain the current value of the total project. However, applying storage is not a separate project but an adaptation of an existing project (namely electricity generation and interchange with the grid of a ZNE-building). Therefore, the calculations are done on the variables which change due to the usage of storage in a ZNE-building, instead of calculating the NPV for the whole building project of a ZNE-building. These are on the one hand the benefits from the overproduced electricity, which are in a situation without net metering higher for stored electricity than for electricity returned to the grid. On the other hand there are costs due to storage investments and maintenance in a situation with storage compared to one without. The total difference in NPV due to storage can be calculated by adding up the NPV of overproduced electricity benefits (NPV_e) and NPV of costs of storage (NPV_s), as displayed in equation 2.

$$NPV = NPV_e + NPV_s \tag{2}$$

The NPV_e is then calculated by discounting the yearly revenue streams of overproduced electricity. In the case of storage there is a differentiation between the electricity stored and later self-consumed, which ‘remunerates’ the consumption price of electricity as it won’t have to be taken from the grid, while electricity returned to the grid will be remunerated with a lower price. When no storage is applied (reference cases), all electricity is returned to the grid and remunerated with the same price. Equation 3 shows the calculation of the NPV_e.

$$NPV_e\ (€) = \sum_{t=0}^{N} \frac{E_{r,t} * P_{r,t} + E_{s,t} * P_{s,t}}{(1+r)^t} \tag{3}$$

$E_{r,t}$ and $E_{s,t}$ are the electricity returned to the grid and the electricity self-consumed by storage respectively, while $P_{r,t}$ and $P_{s,t}$ is the price for electricity returned to the grid and for electricity self-consumed respectively. The discount rate is represented as r. Due to the nature of the NPV_e equation it is always positive, as it only calculates the benefit from produced electricity.

This research assumed the electricity production, demand and overproduction to be similar in all years during the lifetime of the project. Therefor $E_{r,t}$ and $E_{s,t}$ were held equal for all years. $P_{r,t}$ and $P_{s,t}$ were adjusted for each year based on the results from part one of this research.

The NPV_s is calculated by discounting the yearly costs (renewing the technology and maintenance) for the storage technology, as displayed in equation 4.

$$NPV_s\ (€) = \sum_{t=0}^{N} \frac{C_{s,t}}{(1+r)^t} \tag{4}$$

Where $C_{s,t}$ is the cost for the storage technology in year t, where the initial investment in the technology is in year 0. Due to the nature of the NPV_s equation it is always negative, as it only calculates the costs for the storage technology.

4.2.4 Demand Side Management calculations

To calculate the potential of Demand Side Management (DSM) with hot water production in ZNE-buildings it is necessary to identify the current hot water production. From the dataset only high resolution data of the total use was available, so Klimaatgarant as supplier of the heat pumps and responsible for the monitoring of the systems was inquired for average use pattern of the hot water production at the ZNE-buildings in RijswijkBuiten. From this inquiry it became clear that currently the hot water production is started around 23:00, uses 1,2 kWh on average and has a fixed power rate of 1 kW. This energy demand can quite easily be moved to a moment with high solar production, which can be done in two ways:

1. 'Dumb' DSM: The hot water production is moved to a fixed time in the middle of the day, independent of solar electricity production
2. 'Smart' DSM: Hot water production is started when solar electricity production had reached a certain threshold. After this threshold is reached, the water production is continued independent of solar electricity production, as multiple starts and stops of the hot water production will cause inefficiencies. If the threshold is not reached at a predefined time, the hot water production is forced to start to be assured of hot water availability in the house.

The Dumb DSM option is easier to implement, as it only requires the start timer of hot water production to be changed to a different time. The Smart DSM option also requires a connection between the solar monitoring system and the heat pump system and some form of software to be able to start the heat pump based on the solar input. This requires some more thought and also requires investments in this connection between monitoring system and heat pump and in software. The Smart DSM option will result in a higher reduction of the electricity returned to the grid compared to the Dumb DSM option. The algorithms for both options and explanation of the algorithms can be found in Appendix B.

This reduction was analyzed based on different start times for the Dumb DSM and for different thresholds and forced start times for the Smart DSM. From these results, the effect of different settings of the algorithm on the reduction of electricity to the grid can be obtained. Then, the effect of this reduction on the NPV for the households are calculated by taking the difference of the total price for the self-consumed electricity and subtracting the price of the same amount if it would be returned to the grid, as shown in equation 5.

$$NPV_{DSM}\ (€) = \sum_{t=0}^{N} \frac{E_{DSM,t} * P_{s,t} - E_{DSM,t} * P_{r,t}}{(1+r)^t} \tag{5}$$

Where NPV_{DSM} is the Net Present Value of applying DSM in the future, E_{DSM} is the amount of electricity more self-consumed due to DSM every year, while $P_{r,t}$ and $P_{s,t}$ is the price for electricity returned to the grid and for electricity self-consumed respectively. The variables r refers to the discount rate, while N is the total amount of years (which is 30 within this research).

4.2.5 Solar panel orientation calculations

Solar production data of different orientations was obtained from PVGIS database (PVGIS, 2015) which renders monthly solar irradiance data for a specified location in Europe. The input into the PVGIS system is displayed in appendix C. The solar irradiance is obtained in a monthly average W per m^2 for 15 minute intervals. This was translated into irradiance for the given system in RijswijkBuiten by multiplying the total area of solar panels (which is 15 panels of 1.6 m2 forming a total area of 24 square meters). This value has to be multiplied by the efficiency to obtain the actual solar panel electricity production. To identify the efficiency of these panels compared to the solar irradiance data, the actual production data was compared to the irradiance data. The actual production data per month are calculated from the solar PV production data for the terrace house. The efficiency of the solar panels is chosen in such a way that the electricity production from the data matches the theoretical production based on the solar irradiance data. Then the formula to calculate electricity production for a certain orientation from the solar irradiance data is:

$$E_{produced}\left(\frac{kWh}{15\ minutes}\right) = Irradiance\left(\frac{W}{m^2}\right) * Area\ (m^2) * efficiency(\%) * 0{,}25\ hours \tag{6}$$

As previously mentioned, there is only high resolution data (15 minutes steps) available for the interchange with the grid. To match this data with the solar irradiance data, which is only available as average per month, the data from TNO was first averaged per month to obtain an average demand profile for every month on a 15-minute step basis.

To identify the effects of different solar panel orientations, it is important to first obtain the actual demand profile without solar electricity production, which is called here the ‘Gross Demand Profile’. This profile can be used to compare the amount of electricity delivered to the grid for the different orientations. As the solar production profiles are on average per month, this Gross Demand Profile was also generated per month. This is done by taking the average of every 15-minute time step for each month. Next, all consumption data within solar hours were removed and replaced with consumption just outside solar hours, as these indicate the consumption without solar electricity production. This data outside solar hours was extrapolated to the hours with solar electricity production, taking into account that in the early morning (6:30-8:00) the use is higher due to increased activity before the inhabitants leave for work and the use around dinner time (17:00-19:00) is significantly higher due to inhabitants returning home and extra electricity demand for cooking. This resulted in a generated Gross Demand Profile which does not necessarily has to reflect the true consumption profile of the ZNE-buildings. But as consumption profiles can differ significantly per household and the generated profile is used for all different orientations, this generated demand profile will suffice as an indication of real demand data.

After the generation of the actual demand profiles, the solar electricity production profiles were subtracted from these actual demand profiles to obtain the Net Exchange profiles for different solar panel orientations.

5. Financial results

In this section the results of the financial analysis will be discussed. First, the price developments for solar panels, heat pumps and electricity are reviewed, after which the possible net metering adjustments are examined.

5.1 Solar panel prices

The prices of solar panel systems are made up of various components. Most importantly, these are the module price (price of the panels itself), the inverter price and the installation price. The combination of these prices are used in this research to analyze the price development of solar panels.

The prices for solar panels have declined rapidly in the past years, reducing from about €3/Wp installed capacity in 2011 to €1,2/Wp installed capacity in 2015. This high speed in price reduction is likely due to favorable policy developments in Western Europe leading to an high increase in installed capacity and thereby reduction in costs. At the same time, competition in solar panel production from especially China have pushed prices down. These extreme price reductions have not been foreseen by leading research organizations on solar panels. For example ECN (2009) and The European Photovoltaic Technology Platform (EUPVplatform, 2009) expected in 2009 that the price of solar panel systems would be around €2/Wp installed capacity in 2020. The expectation of €2/Wp was already achieved in 2012, while prices have lowered to €1,2/Wp in 2015.

Due to this unexpected price decrease the future prices of solar panels will be estimated using a best fitting trend line on the data of the previous 5 years. Data points which indicated solar system prices throughout these years are obtained from three organizations which have gathered data of solar system pricing over the last few years. These organizations are ZonnestroomNL, CompareMySolar and the German Solar Industry Association (German: *Bundesverband Solarwirtschaft*, BSW). All of these organizations have not yet reported on price developments over the year 2014. To complement their data with the latest developments, two extra sources (Klimaatgarant and Zonnepanelen.net) have been added which reflect the latest price for a PV system. Klimaatgarant is the supplier which has delivered the solar panels for the ZNE-buildings in RijswijkBuiten, while Zonnepanelen.net shows the current prices based on an indexation of various suppliers. These five sources are used to obtain the best fitting trend line, which is a logarithmic trend line. Data points and trend line are shown in figure 4.

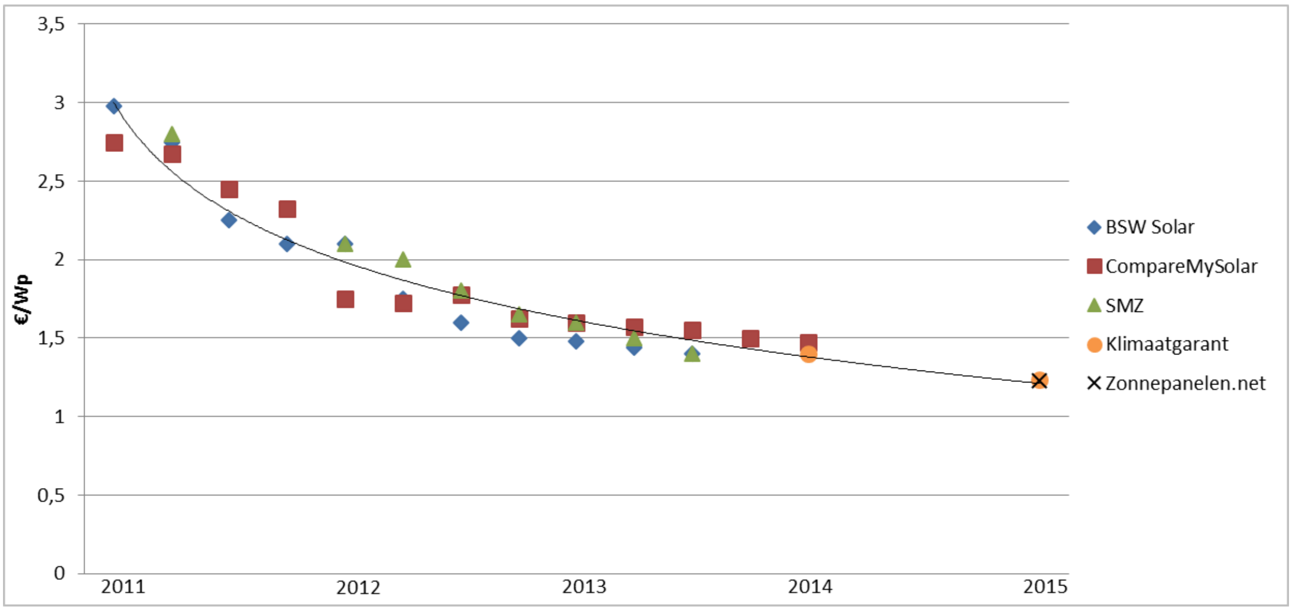

Figure 4: Average price of household solar systems (module, inverter and installation) without tax per year for systems between 3 kWp and 5 kWp.

The trend line which is obtained from can be extrapolated to 2020 to obtain price values for that year. This results in a price of €0,723/Wp[1]. For the current systems of 3,9 kWp which is used in the ZNE-buildings in RijswijkBuiten, this results in a total price of €2822. The current price for PV panels is €4810. This indicates that if the price keep declining according to the estimated trend line, a cost saving of almost €1988 (excluding VAT) can be obtained.

5.2 Heat pump prices

As discussed in the background, the prices of heat pumps depend on a lot of factors. Such as the heat pump itself, but also piping requirements and the drilling of a source. There are also large differences between the types of heat pumps (air-air, air-water or water-ground) and the type of project (new buildings or renovations and the amount of houses which are provided with heat pumps at the same time). This results in a lot of sources giving a large range of prices for heat pumps. For example, the prices showed by the Governmental Organization for Entrepreneurship (Dutch: *Rijksdienst Voor Ondernemend Nederland*, RVO) ranged between €10.000 and €16.150 depending on type and project size (RVO, 2008). More recent sources also show a large range in total system prices, while the characteristics of the project remain unclear. Ranges mentioned by PBL (2014) are €9.350 to €12.650 and by DWA (2014) from €10.000 to €12.500. These prices can thus differ between 25% and 35% within their respective ranges. Due to this unclarity in prices and the price being very dependent on the specific project, this research will solely use recent cost data from heat pumps in RijswijkBuiten. Klimaatgarant has been the supplier for RijswijkBuiten, where the installed heat pump system (excluding drilling of the source) were approximately €7.700 in 2014

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[1] It is important to note that there is discussion between experts in the solar industry whether we continue on the current price path. This is because until now the price of the modules has dropped significantly, but it is argued there is much less leeway for price drops in modules in the future. The share of labor (installation costs) becomes relatively higher but costs reductions here are said to be much harder to be obtained. On the other hand, ECN (2009) expects the prices for a total system to become even lower in the future compared to the results of this research: €0,5/Wp. Another important factor which will affect the solar panel price in 2020 will the minimum price the European Union imposes on Chinese solar panels. This is currently €0.56 per Wp for the modules alone. If this minimum price will be maintained towards 2020, it is unlikely that the turn-key price will reduce towards €0,723/Wp, as the international competition of module prices is reduced due to this minimum price.

and €7.500 in 2015. This indicates an cost decrease of 2,6%, which will be used for extrapolating costs to 2020. If done so, this results in €6574,7 in 2020 for the system (excluding drilling of the source). As any data is lacking, there are no cost reductions on the drilling of the source taken into account. The total cost reduction towards 2020 then adds up to €925 (excluding VAT).

5.3 Electricity price

The background section shows that the electricity price which consumer pay. Therefore the following components and their trends need to be discussed: market price, supplier surplus, energy tax and VAT.

5.3.1 Market price & suppliers premium

The market price of electricity is here defined as an average price during the day. The market price of electricity has seen a steady increase until 2008 to €0,063/kWh, after which the base load prices have significantly reduced towards 2010 to €0,048/kWh due to the financial crisis. From 2010 to 2014 the prices increased and decreased slightly, resulting in a price slightly above and below €0,05/kWh. Long-term contracts show a slight increase in electricity price towards €0,0515/kWh for contract in 2019. This equates to a average increase in the market price of electricity of 1,23% for 2015 to 2019. The suppliers price (the electricity price paid by consumers to their electricity supplier, without taxes) is directly correlated to this market price, as the market price is the major share in costs for electricity suppliers. The suppliers price is higher due to company costs, profit margin and extra costs for peak pricing for electricity suppliers. The correlation between market price and suppliers price can be seen from a historical outline of the market price and suppliers price between 2009 and 2014, which is shown in figure 5. The same figure also shows the long-term contract pricing. Due to this correlation, this research will assume that the suppliers price will change with the same percentage as the market price.

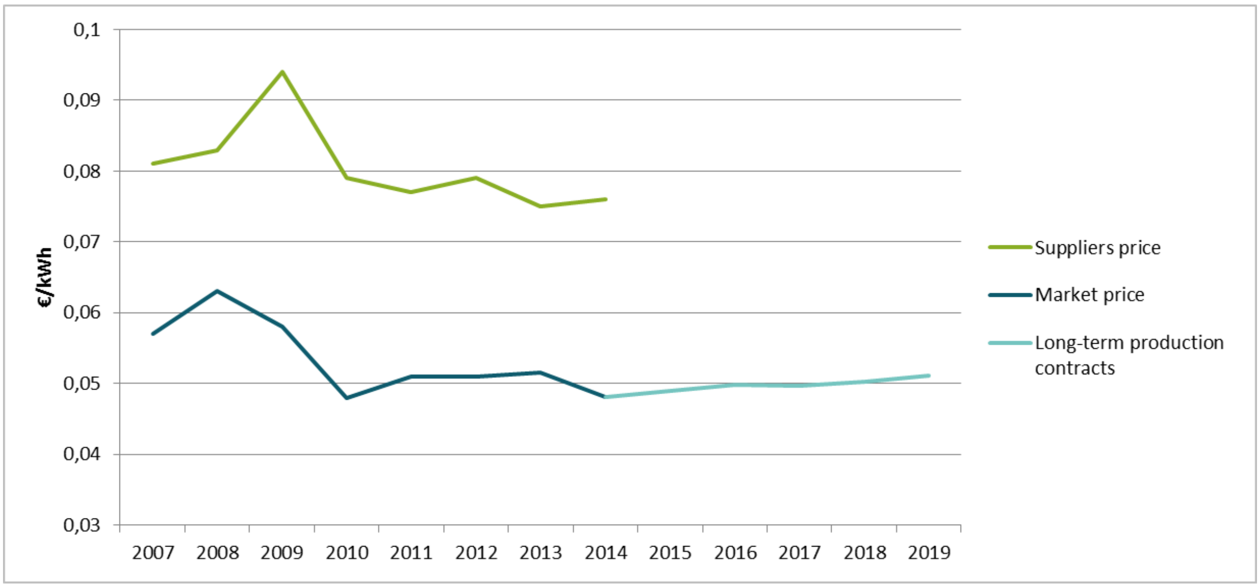

Figure 5: Market price, suppliers price and long-term contracts price between 2009 and 2019

Whether the actual market price will follow this slight increase of 1,23% as the long-term contracts show is open to debate. As the general trend before 2007 has been upward, some research institutions take into account that in the longer term the electricity price will increase. VNG (2013) expects the market price to be €0,062/kWh in 2020, while ECN (2009) expects it to be €0,065/kWh in 2020. On the other hand, some institutions mention the changing market dynamics as more renewable capacity is installed as a possible downward pressure on the market price of electricity. Research institute CE Delft (2009) analyzed that due to an increase in available capacity the market price would continue to be under pressure. CE Delft suggests that on the long-term the electricity price is not likely to increase at the same pace as before 2007 due this overcapacity. The National Energy Exploration, a study into trends in energy use and pricing from the Netherlands Environmental Assessment Agency (PBL, 2014) showed that due to an increase in renewable sources with low marginal costs, the market price of electricity after 2020 will not increase significantly. On the other hand, increased penetration of heat pumps and electric vehicles will lead to an overall increase in electricity demand and thereby an upward pressure on the electricity price. Additionally, recovery of the economy may also increase the demand for electricity and the market price. Due to this uncertainty in development of the market price, it is difficult to accurately assume what the market price will do towards 2020 and after 2020. Following PBL and CE Delft a moderate increasing electricity price is assumed: an average price increase of 1% is based on the long-term contracts and will be used for extrapolation of the electricity price. This will be the ‘low’ scenario in electricity price developments.

Merosch has been using the development of the electricity price from 2000 onwards. The average increase in electricity price between 2000 and 2013 has been 5% per year. They have been calculating business cases using a more moderate 3% increase per year. As some business calculations on RijswijkBuiten have also used this 3% increase per year, this will also be taken into account as scenario in this research. The 3% price increase per year will be the ‘high’ scenario in electricity price developments.

As discussed before, due to the correlation between suppliers price and market price, this research will assume that the suppliers price will change with the same percentage as the market price.

5.3.2 Energy tax

The energy tax constitutes a large share in the total electricity price of households, covering about 50% of the total variable price which households pay. The energy tax is currently €0,1196/kWh (Belastingdienst, 2015). Since 2010, the energy tax has increased with 1,6% on average. The developments in energy tax between 2009 and 2015 is shown in figure 6.

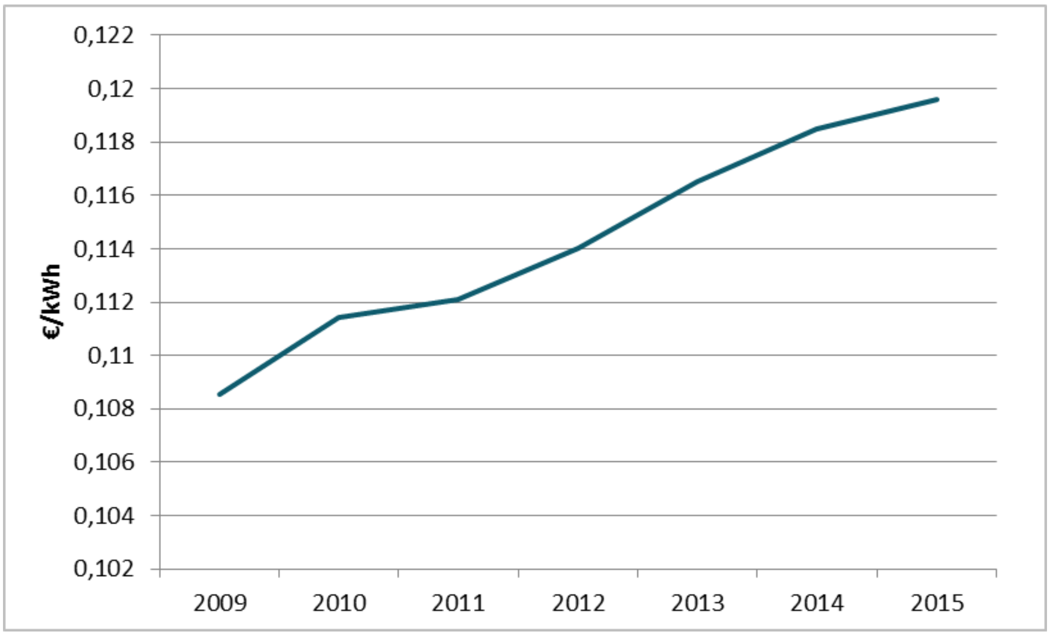

Figure 6: Energy tax since 2009 and increase in energy tax as percentage (Belastingdienst, 2015).

However, in an extensive agreement (called the Energy Agreement, Dutch: Energieakkoord) between the government, several social organizations and market parties, it was agreed that some decisions in this agreement would be paid by an increase in energy tax. Therefore, it could be possible that the energy tax will show a higher increase the coming years to cover the costs for decisions in the Energy Agreement. Therefore, an average increase in energy tax of 2% per year will be used for extrapolating the energy tax towards the future. This increase will be used in the 'low' scenario, while an increase of 3% per year as used in other extrapolations by Merosch will be used In the 'high' scenario (as discussed in 4.3.1).

5.3.3 VAT

The VAT in the Netherlands is for all products and services 21%, except for products and services which have are exempt from this high VAT tariff and only require a low VAT tariff of 6% (such as food and public passenger transport). Electricity is priced in the high tariff of 21%. This high tax rate has been changed in 2012 from 19% to the current 21%. As the 19% tax tariff has been in place for 11 years (from 2001 to 2012), it is likely that the current VAT tariff will be in place for the coming years.

5.3.4 Scenarios for electricity price developments

The developments in market price, suppliers price, energy tax and VAT are incorporated into two scenarios which will be used for calculation on the future price of electricity. The first scenario ('low scenario') is a scenario based on developments in the recent years (2009-2015) and takes into account a small increase in market price and suppliers price and a higher increase in energy tax, while the VAT is constant. The second scenario ('high scenario') is based on the calculating as is done for similar projects, which takes into account an overall average price increase of electricity of 3% per year, as is also used by Merosch. This will be taken into account to analyze the effects of changes in net metering based on original calculations on the increase in electricity price. The scenarios and changes for the different subsections of the electricity price are displayed in table 3.

Table 3: Scenarios of development of the electricity price

Scenario	Effects on electricity price
Low	Increase in price of 1 % increase/year for consumer price and market price
High	Increase in price of 3 % increase/year for consumer price and market price

5.4 Net metering adjustments

Based on different sources, both interviews and reports, two scenarios were constructed for adjustments in net metering. The interviews were used as background information on the background of the current net metering regulation and current developments in revising this regulation. The reports and transcripts were used to pick two scenarios which could be implemented after 2020.

5.4.1 Net metering adjustments interviews

The interviews were used to get a basic insight into the ideas of politicians and civil servants on net metering. This insight was used to construct possibilities for net metering adjustments. This sections provides a short indication of the ideas of the interviewees.

The interviewees all had a good understanding of the current situation around net metering and the problems it faces. They indicated that indicated that the current system of net metering is not viable in the long run. Due to the recent drop in costs the original incentive, making the placement of PV systems cheaper, is no longer necessary and will result in a undesirable incentive from a system perspective:

> *“The net metering regulation is an undesirable incentive where the government is covering an increasing share of the installation costs of individual roof systems. It results in an increasing pressure on the infrastructure while not incentivizing any form of smart solutions for the energy system as a whole.”*

The interviewees argued that this idea did not fully arrive at the responsible ministries, but will soon be entering the way of thinking around net metering. It is argued that the most important ‘red flag’ for the ministries of Economic Affairs and Finance will be the increasing loss of revenues from energy tax, as the solar capacity in the Netherlands is growing rapidly.

> *“The ministry of Finance now thinks: 150 million is still acceptable, we will just watch it the coming years. But due to the high increase in PV systems, there is suddenly a high increase in use of the net metering regulation too. Then the realization comes that something has to be done and the negotiations with the Lower Chamber starts to abolish the regulation. “*

The idea that something should and will be done is present in the political area is clear considering the statements of Minister Kamp regarding the net metering regulation and adjustments. While the minister stated that some sort of transitional arrangement will be made for the years after 2020, some interviewees indicated that a direct abolishment of the regulation is likely to be an option as well:

> *“I can imagine that they will say: in 2020 we will stop the regulation entirely. You can’t say immediately: tomorrow we will pull the plug, but if you declare up front: this regulation will stop in 2020, you can prevent difficult transitional arrangements.”*

But in the end, none of the interviewees could convincingly state that a specific adjustment scheme would be used for the period after 2020. They argued that the process of revising the net metering regulation depended very heavily on the political interaction and outcomes. It is the weighing of different interests which will result in the way in which the government will abolish net metering regulation.

> *“I do not know what will be the most likely scenario for net metering adjustments. It heavily depends on the choices made in the Lower Chamber. There has to be support from enough parties to come to a specific adjustment of net metering.”*

5.4.2 Net metering adjustment scenarios

From the interviews it was concluded that there was no specific adjustment in the net metering regulation which was already specifically mentioned as most likely scenario. Therefore, multiple scenarios will be used to analyze the effect of different kinds of net metering adjustments. The in-depth study into net metering regulation from Van der Water (2014) uses three different types of adjustment scenarios:

- Current net metering regulation is replaced with a fixed tax reduction
- Current net metering regulation is abolished
- Current net metering regulation is replaced with a tax reduction which declines in time

The first scenario takes into account a fixed tax reduction on electricity which has been returned to the grid and is taken from the grid on a later time. Electricity returned to the grid will not only remunerate the market price in this scenario, but it also yields ‘rights’ to buy electricity from the grid with a fixed tax reduction. This tax reduction can be set at various amounts, but would likely be similar to other programs. One similar program is the Dutch *postcoderoos* regulation, which is a tax reduction for renewable electricity produced within the neighborhood. It is assumed that the fixed tax reduction will be set equal to the current regulation on local renewable production under the *postcoderoos* regulation, which is a reduction of €0,075/kWh. In the second scenario, the net metering regulation will be abolished from 2020 onwards, which results in solar electricity returned to the grid only being remunerated by the market price of electricity. The third scenario uses a declining tax reduction over time. Two variables in this scenario are the total time of declining tax reduction and the speed of the tax reduction. Minister Kamp already stated that in case of some sort transitional scheme, a the total transitional period of four years would be deemed fair (Tweede Kamer, 2014). As the current benefits are about €0,17/kWh, this would indicate that the first year of the transitional period the benefit will be reduced to €0,14/kWh, the second year to €0,11/kWh, the third year €0,07/kWh while the fourth year the tax reduction would only be €0,04/kWh. From the fifth year and onward there would be no tax reduction anymore and solar electricity which is returned to the grid will only be remunerated with the market price. As the business cases of ZNE-buildings are calculated over a time period of 30 years, this 4 year transitional period will not significantly change the total remuneration for electricity returned to the grid compared to the second scenario. To keep the results of this research easily interpretable, this third scenario will therefore not be taken into account.

In total three scenarios will be calculated to analyze the effects of adjustments in net metering on the business case of ZNE-buildings. The first and second scenario are equal to those of Van der Water (2014), while the last scenario will be a reference scenario to calculate the situation without any adjustments in net metering regulation. The different scenarios and assumptions are displayed in table 4.

Table 4: Remuneration for solar electricity per scenario

Scenario	Immediately consumed	Returned to the grid, later consumed	Excess electricity produced
Fixed tax reduction	Consumer price	Market price + €0,075/kWh	Market price
No tax reduction	Consumer price	Market price	Market price
Reference	Consumer price	Consumer price	Market price

5.5 NPV effect of financial trends under different net metering adjustments

Taking the price trends of both the energy related equipment and electricity into account, the NPV for households can be calculated if a ZNE-building similar to those of RijswijkBuiten are built in 2020. The total price reduction of energy related equipment is €1988 for the solar panels and €925 for the heat pump, totaling to €2913 (excluding VAT). Including VAT this is a reduction of €3525, which equals the NPV as it is an initial investment.

Using the price development scenarios and net metering adjustment scenarios, the NPV value of overproduced electricity can be calculated for a scenarios with net metering and without net metering adjustments. The difference between these two indicates the NPV loss due to net metering adjustments. The results of the NPV calculations for different scenarios are shown in table 5.

Table 5: NPV of overproduced electricity for different scenarios.

		Net metering adjustment		
		Abolishment	Fixed tax reduction	No adjustment
Price increase	Low increase	€ 2.343	€ 5.398	€ 10.575
	High increase	€ 3.293	€ 6.348	€ 14.863

The combined results for the price reduction of energy related equipment and the NPV of overproduced electricity show the NPV gap which arises due to net metering adjustments for different scenarios. These values are displayed in table 6.

Table 6: Gap in NPV due to net metering adjustments, taking into account price reduction energy related equipment

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 4.707	€ 1.652
	High increase	€ 8.045	€ 4.990

The results of table 5 and table 6 are shown in figure 7.

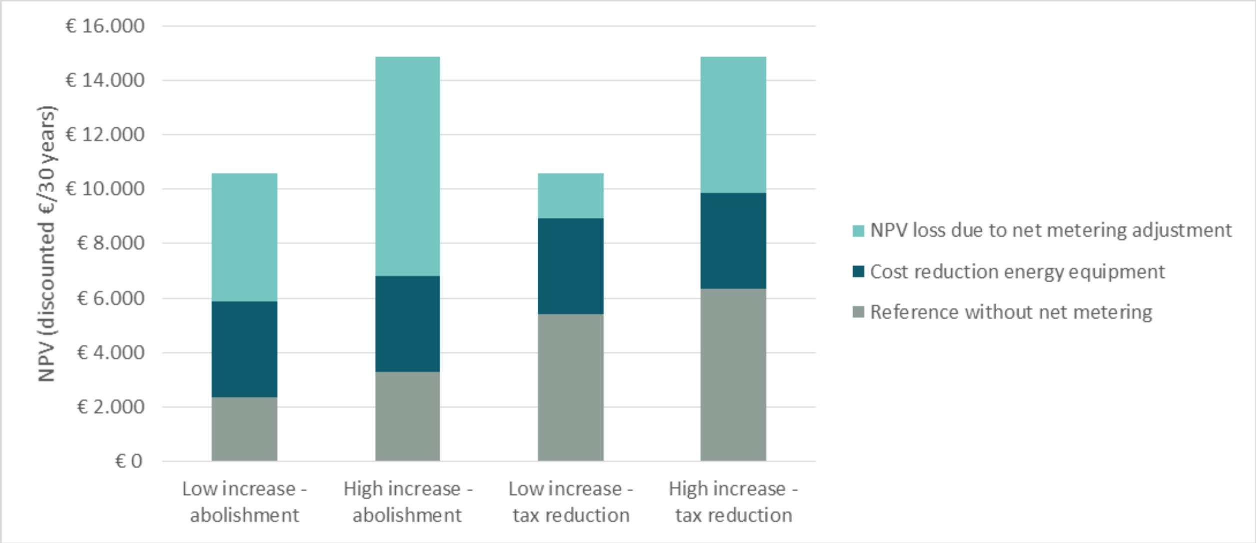

Figure 7: NPV breakdown of effect of adjustment in net metering
The whole bar illustrates the NPV of electricity under current net metering regulation.
The grey section shows the NPV of electricity under adjusted net metering regulation
The dark blue section shows the NPV improvement due to cost reduction.
The light blue section shows the remaining loss of NPV due to net metering adjustments.

6. Technological results

In this section the results of the technological solutions are discussed. The technological solutions which are reviewed are: (electricity) storage, Demand Side Management and differentiating solar panel orientations.

6.1 Storage results

6.1.1 Storage requirements

To obtain the potential of storage devices for ZNE-buildings it is necessary to first identify the potential storage technologies for such an application as well as their characteristics. To make this analysis as inclusive as possible, all storage technologies are reviewed on their suitability for small storage at residential sites. One of the types of storage which is often mentioned for household storage is using the battery of electric vehicles which are owned by inhabitants. This provides a large storage medium without extra investment costs (if the car is already owned by the inhabitants). However, there are some drawbacks to using electric vehicles as day to day household storage medium. It reduces the lifetime of the battery and it requires all households to drive with electric vehicles. But most importantly, if the car is used as daily transport, it is often not available during solar hours, where it is supposed to store the excess solar electricity production. For these drawbacks, storage in electric vehicles is not taken into account.

The first step towards analyzing the best suitable storage technology is analyzing the requirements of storage technologies for ZNE-buildings. The storage type which will be analyzed in this report is daily storage, to store the overproduction of solar electricity of one day to be used in the evening/night. Seasonal storage will require much larger volumes, as the overproduction of multiple months in the summer should be stored for use in multiple months in the winter. For daily storage, the total production of a ZNE-building being stored per day is the maximum storage requirement. The ZNE-buildings in RijswijkBuiten produce about 15 kWh on a very sunny summer day. Therefore, the maximum storage size would be 15 kWh. As it is the goal to obtain an optimal storage size, the storage technology should be sizable between 1 and 15 kWh. Additionally, storage devices will typically lose some of the stored energy in the storing process. The efficiency of storage should not be lower than 80%, as to make sure that these buildings keep being Zero Net Energy without adding a lot of solar panels to compensate for the loss in stored electricity. The storage technology will be used to store energy over a longer period and not to balance the power within the house. It will be taken into account whether the storage technology is used for balancing power or for storing energy.

6.1.2 Types of storage

The characteristics of the main types of energy storage can be found in Table 7. Based on these characteristics a subsection of storage technologies will be further investigated.

Table 7: Overview of characteristics of different storage technologies
Sources: Ecofys, 2014; TU Delft, 2015; DNV KEMA, 2013; Utrecht University, 2014; ISEA, 2012.

Technology	Investment costs (€/kWh)	Typical storage amount (kWh)	Efficiency (%)	Typical use
Pumped Hydro	400-4.000	>1000 kWh	50-85	Energy Storage
Compressed Air Storage	2-430	>1000 kWh	27-70	Energy Storage
Flywheels	100-400	1-10 kWh	90-95	Power storage
Hydrogen storage	400-600	100->1000 kWh	22-50	Energy Storage
Flow batteries	150-1.350	10-100 kWh	60-75	Energy Storage
Solid state/liquid batteries	250-4.000	1-100 kWh	75-95	Energy Storage
Super capacitors	300-2.000	0,01-1 kWh	90-95	Power storage

Based on the storage size requirement (<15 kWh) and efficiency requirement (>80%) pumped hydro, Compressed air storage and Hydrogen Storage are excluded. Based on the use of the storage technology to store significant amounts of energy for a longer period of time, flywheels and super capacitors are excluded. Based on the efficiency requirement flow batteries are excluded. That leaves only the type solid state and liquid batteries as possible storage solution.

6.1.3 Types of batteries

There is a varied range of solid state and liquid batteries. Based on the before mentioned requirements of size, efficiency and typical use, there is a selection made of 3 types of storage technologies which will be reviewed for application at ZNE-buildings:

- Lead-acid: batteries which uses lead and dissolved sulfate. Mainly used in car batteries due to the high power it can provide against relatively low costs.
- Lithium-Ion batteries: uses lithium-ions as main charge carrier. Used extensively in portable consumer electronics due to its high energy capacity compared to its size.
- Sodium-Ion: Relatively new type of battery which uses sodium as charge component. Currently in the development stage with only a small amount of market batteries available.

The investment costs and efficiency of different sources for these three battery technologies are displayed in Table 8. This is combined with the maturity of the technology, where a high maturity signifies that the technology is widely used in different application, while low maturity conveys that the technology is in development and demonstration level and is not yet used in large quantities.

Table 8: Overview of solid state end liquid battery technologies

Technology	Investment costs (€/kWh)			Efficiency (%)			Maturity
	Ecofys (2014)	TU Delft (2015)	DNV KEMA (2013)	Ecofys (2014)	TU Delft (2015)	DNV KEMA (2013)	TU Delft (2015)
Lead-Acid	300-3300	125-1150	-	75-90	70-90	70-85	High
Lithium-ion	770-5300	250-2500	300-2300	87-94	75-95	90-95	High
Sodium-ion	-	100-200	-	-	83-90	-	Low

Each technology has its own advantages and disadvantages. Lead-acid combines low costs with high maturity, while Lithium-Ion has higher costs but also a higher efficiency. Sodium-ion is a new technology which is still under development, in contrast to lead-acid and lithium-ion are fully market tested and have been produced and applied on large scale. Due to the development stage the sodium-ion battery technology is still in, it is unclear whether these batteries will live up to the projections by manufacturers. The sodium-ion battery can be an interesting option in the future, but due to this lack of maturity it will not be taken into account in this research.

Except for investment costs and efficiency, there are more indicators which should be taken into account when weighing different technologies. These are the discharge depth, lifetime cycles and possible safety issues. The discharge depth should be high, so to be able to use more of the capacity of the battery. The lifetime cycles should also be high, as the technology has to be used over multiple years by the household. Discharge depth, lifetime cycles and safety issues are displayed in table 9.

Table 9: Discharge depth and lifetime cycles for different battery technologies

Technology	Discharge depth	Lifetime cycles
Lead-acid	75%-80%	500-1000
Lithium-ion	90%-100%	500-5000

Based on the data in table 9, it is clearly shown that the characteristics favor the lithium-ion battery, with a higher discharge depth and longer lifetime. Especially the lifetime will be a problem when using Lead-acid batteries, as it requires much more frequent replacement of the battery.

6.1.4 Lithium-ion battery characteristics input

There are still large differences in the specifications for Lithium-Ion batteries due to very different function of the batteries. This research will focus solely on stationary batteries in the range of 0,5 and 20 kWh with a high lifetime and efficiency. The costs, efficiency and lifetime cycles differ a lot. Therefore, a reference lithium-ion battery is used as input for the data. To use the most recent developments, the new Tesla home battery will be used as reference battery. The specifications of this battery are displayed in Table 10.

Table 10: Specifications Tesla's Home Battery Pack (Tesla, 2015)

Characteristic	Value
Capacity	7 kWh or 10 kWh
Price	€ 382/kWh or € 312/kWh
Round trip efficiency	>92 %
Power production	Continuous: 2 kW, peak: 3 kW
Operating temperature	-20 °C to 43 °C
Warranty	10 years[2]
Maintenance costs	Not required/not specified

From table 10 the round trip efficiency and warranty are used within the storage model. The round trip efficiency is stated as higher than 92%, which will be assumed to be 95% on average. However, this does not include the efficiency of the inverter which has to invert AC to DC power. Such an inverter will also have a efficiency of about 95% on average one way (Muñoz et al., 2011), which results in a total system efficiency of 95%*95%*95% = 86%. This efficiency will be used in the model. The warranty is assumed to be the lifetime of the battery pack, thus 10 years will be used as lifetime of the battery within the model. However, at low installed capacity (>2 kWh a day) the battery can be charged and discharged multiple times a day, which increased the wear down on the battery. Therefore, a maximum amount of full load cycles of 3000 (TUDelft, 2015) is used as lifetime or the maximum amount of 10 years.

The data provided by Tesla on the Powerwall battery system include a discrete amount of storage capacity and the current price for the system. These variables were not used, as this research looks into the optimal storage size which could also be lower than the minimal storage size of the Powerwall or lie between the 7 kWh and 10 kWh size. Therefore, it is assumed that near 2020 there will be a battery technology which is scalable on a 0,5 kWh basis and this research is optimizing on 0,5 kWh intervals. The current price is expected to reduce the coming years, as this is the initial battery pack and more competition and a growing market will put pressure on the price. To obtain the expected price of battery storage in 2020, multiple scientific and market reports have been consulted on their 2020 lithium-ion battery price. The estimates from these sources are displayed in table 11.

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[2] Current battery systems do not provide for daily storage and discharge with such a high lifetime. Tesla is said to have some measures in place to prolong the lifetime, but it is not yet shown to actually provide such a long lifetime. However, during the coming years it is likely that battery technologies will improve in their lifetime due to a larger market for home storage.

Table 11: Cost estimations for Li-Ion batteries in 2020

Authority	Estimate	Estimation type	Source
Avicenne Energy	€ 250/kWh	Estimation	Pillot (2014)
Rocky Mountain Institute	€ 270/kWh	Estimation	Bronski et al. (2014)
Advanced Automotive Batteries	€ 170/kWh	Estimation	Anderman (2014)
University of Delaware	€ 190/kWh	Estimation	Budischak et al. (2012)
Tesla	€ 180/kWh	Target	Luxresearch (2014)
Average 2020 estimates	€ 212/kWh	-	-

The individual estimates differ up to 27% of the average of the five estimates. However, all estimates show a significant decrease in price compared to the current price of the Tesla Powerwall. The average price of the 2020 estimates of €212/kWh of storage capacity will be used within the storage model.

6.1.5 Storage potential

Based on these input variables, the storage algorithm calculated the storage potential of different storage sizes for a reference of 2650 kWh overproduction. The results are shown in figure 8.

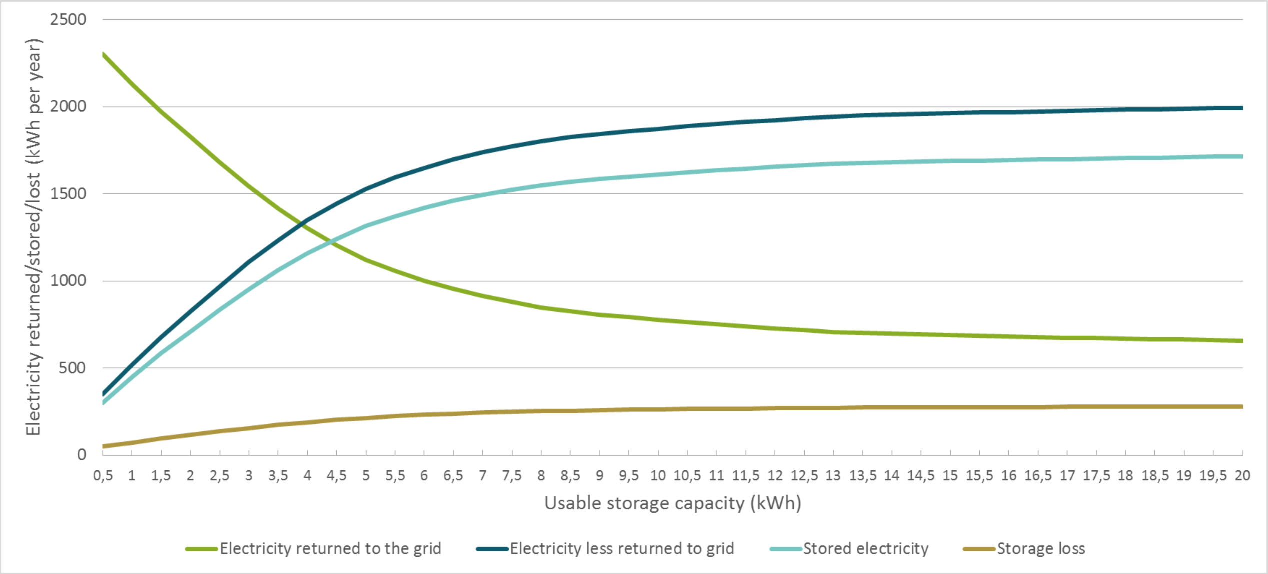


Figure 8: Electricity returned to the grid, electricity stored and electricity lost in storage process for different storage sizes.

Figure 8 shows that the first few kWh of storage size has a large effect on the amount of electricity stored per year. Around 5 kWh there is a significant drop in amount of electricity extra stored per kWh extra storage capacity, while around 13 kWh there is a very small amount of extra electricity stored per kWh extra storage capacity. This indicates that the first few kWh are the most interesting due to their large incremental storage potential.

6.1.6 Economic optimum

The results from figure 8 can be translated into an economic optimum by taking into account the battery price, lifetime and benefits of increasing the self-consumption of electricity. For this purpose the battery price and lifetime from section 6.1.5 are used. The electricity price is extracted from the financial results of this research, which are a market price of electricity of €0,0514/kWh and €0,232/kWh for the consumer price. The electricity price scenarios (low: 1%/year, high: 3%/year) of the first part were used to obtain the electricity part for the lifetime of the analysis. The discount rate was set to 5%/year and the total overproduction of electricity was set to 2650 kWh per year, which is the indication of the average overproduction over the lifetime of 30 years. All the input variables for the storage algorithm can be found in Appendix D.

The results of this NPV calculation in the low electricity price scenario is displayed in figure 9, while the results of the high scenario can be found in figure 10.

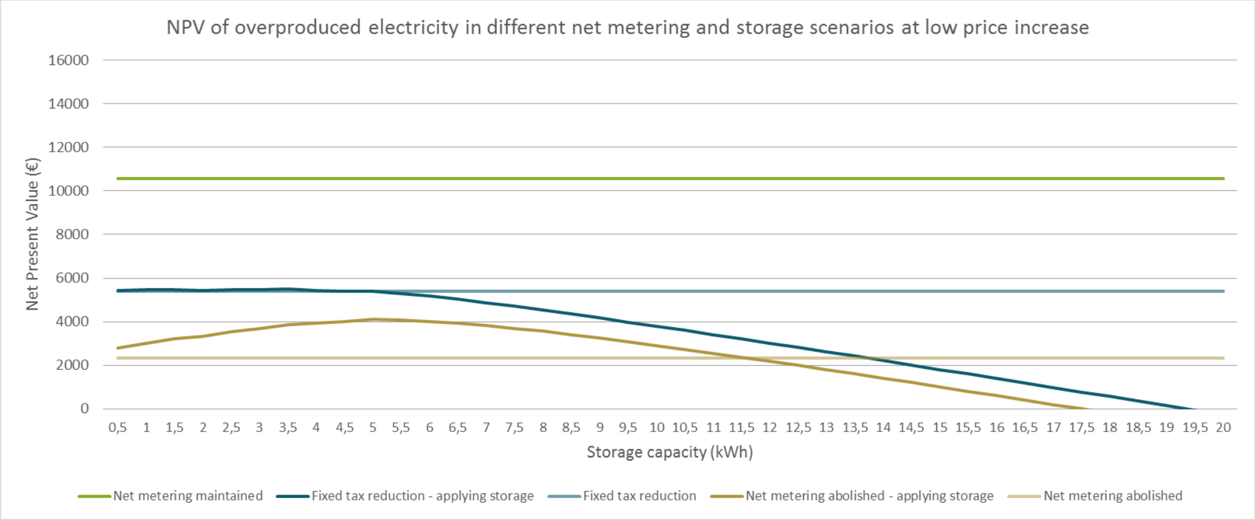


Figure 9: NPV of overproduced electricity in different net metering and storage scenarios at low price increase

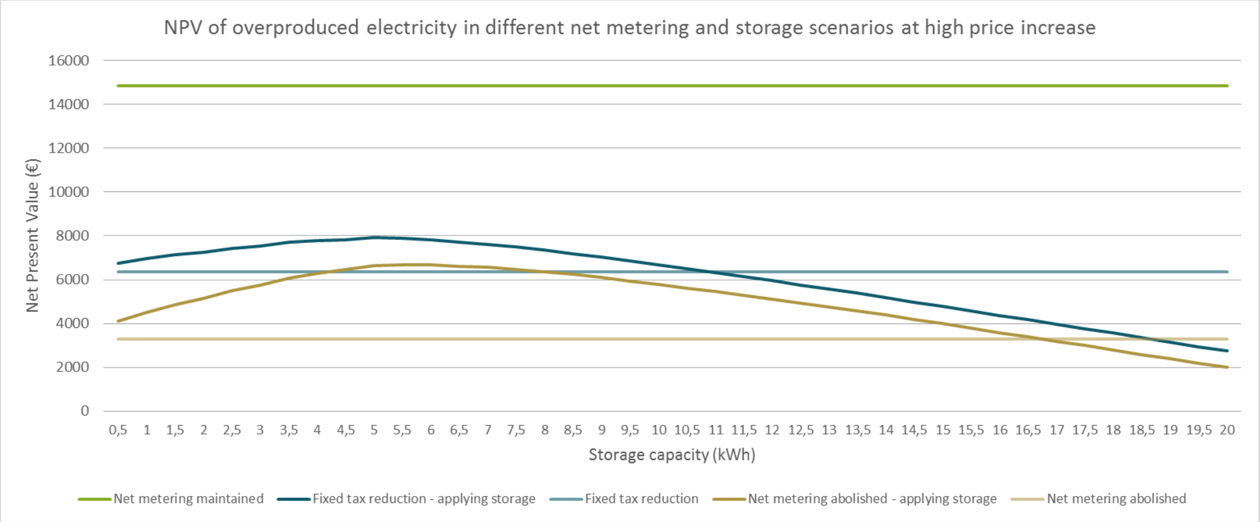


Figure 10: NPV of overproduced electricity in different net metering and storage scenarios at high price increase

It can clearly be seen in both figures that initially the NPV is increasing for both net metering scenarios, which goes to a certain maximum between 3 and 6 kWh of storage capacity, after which the NPV decreases significantly with each added kWh of storage capacity. This indicates that storage capacity added is more costly than the benefits from returning less electricity to the grid. From figure 9 can be seen that the low price increase scenario combined with the tax reduction scenario gives a rather flat NPV curve over the first few kWh installed capacity. Therefore, the storage size with the highest NPV is very similar in NPV to storage sizes above and below it. For the other scenario combinations there is a much more clear optimal storage capacity. It is also clear that due to the higher energy price increase in figure 10, the NPV for all scenarios is considerably higher. This is due to the fact that electricity gets more expensive faster, resulting in a higher NPV over 30 years. The last important insight from these graphs is that storage could result in a considerably higher NPV compared to both net metering adjustments, but still results in large decrease in NPV compared to when net metering would be maintained.

Based on these graphs (and the underlying numerical results) an optimum can be identified which maximizes the NPV of the overproduced electricity by applying the storage capacity which renders the highest NPV. The results of this NPV maximization for the two electricity price increase and the two net metering adjustment scenarios are displayed in table 12 and visualized in figure 11.

Table 12: NPV and NPV difference of different scenarios and for optimal storage size
NPV for 30 years with 5% discount rate.

Result	Low increase - abolishment	High increase - abolishment	Low increase - tax reduction	High increase - tax reduction
Reference electricity NPV	€ 10.575	€ 14.863	€ 10.575	€ 14.863
No storage electricity NPV	€ 2.343	€ 3.293	€ 5.398	€ 6.348
Cost reduction of energy equipment	€ 3.525	€ 3.525	€ 3.525	€ 3.525
NPV difference without storage	-€ 4.707	-€ 8.045	-€ 1.652	-€ 4.990
Optimal battery size	5 kWh	5,5 kWh	3,5 kWh	5 kWh
Electricity stored	1314 kWh	1371 kWh	1061 kWh	1314 kWh
Electricity lost in storage process	214 kWh	223 kWh	173 kWh	214 kWh
Electricity returned to the grid	1122 kWh	1056 kWh	1416 kWh	1122 kWh
Self-consumption increase	49,6%	51,7%	40,0%	49,6%
NPV including storage	€ 4.111	€ 6.678	€ 5.487	€ 7.933
NPV increase due to storage	€ 1.768	€ 3.385	€ 89	€ 1.585

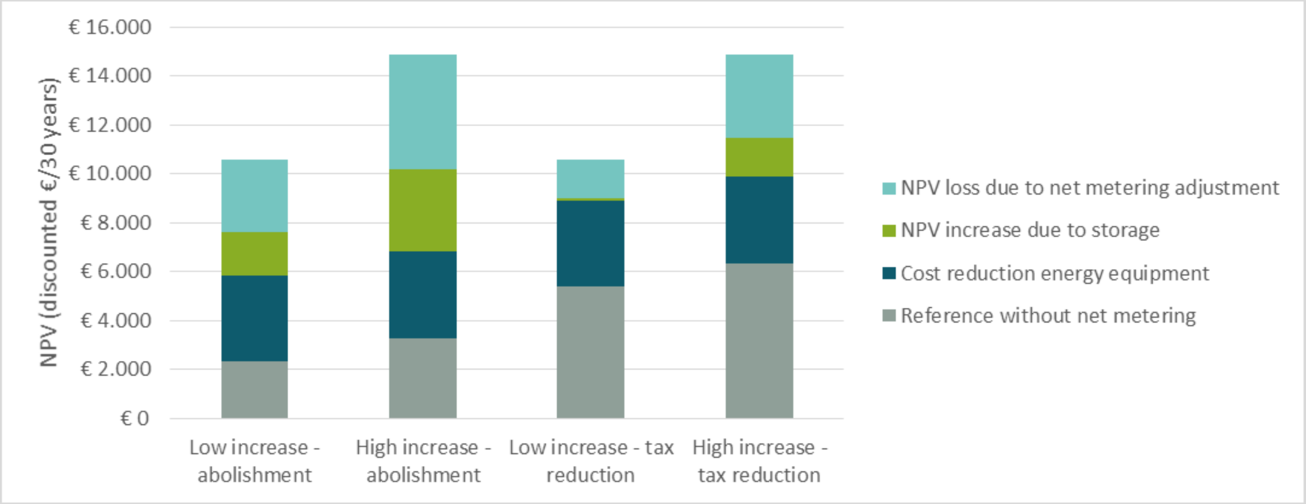


Figure 11: NPV breakdown of adjustments in net metering including storage (effect of storage in green)
Breakdown is similar to figure 7, while NPV improvements of storage (green) is added.

From table 12 and figure 11 can be seen that the optimal size of the battery is higher in a higher price increase scenario compared to a low price increase scenario. It also shows that the self-consumption increase of the electricity which is currently returned to the grid is between 40% and 52%, which is a significant share. Combined with the loss, this even increases to between 50% and 62% less electricity returned to the grid. However, due to storage costs and electricity losses in the storage process, the NPV increase due to storage is limited to between 20% and 30% of the reference NPV loss due to net metering adjustments in all scenarios, except for the low price increase with tax reduction scenario, where it is only 2%. Storage will thus largely reduce the amount of electricity returned to the grid, but the reduction in NPV loss is not remotely the same if compared in percentages.

6.2 Demand Side Management

The second technological solution is Demand Side Management (DSM). Within this research this means rescheduling the hot water production which is currently scheduled at the end of the evening towards hours with solar energy production. Currently there is an average use of 1,2 kWh per day, thus resulting in a maximum DSM potential of 1,2 * 365 days = 438 kWh. As discussed in the methodology, this research will discuss two ways in which DSM is applied: a 'dumb' way and a 'smart' way. The Dumb DSM is rescheduling the hot water production to a preset time around noon, while the Smart DSM variant starts hot water production based on solar electricity overproduction. The effects of these two DSM options on the average yearly demand profile are shown in figure 12.

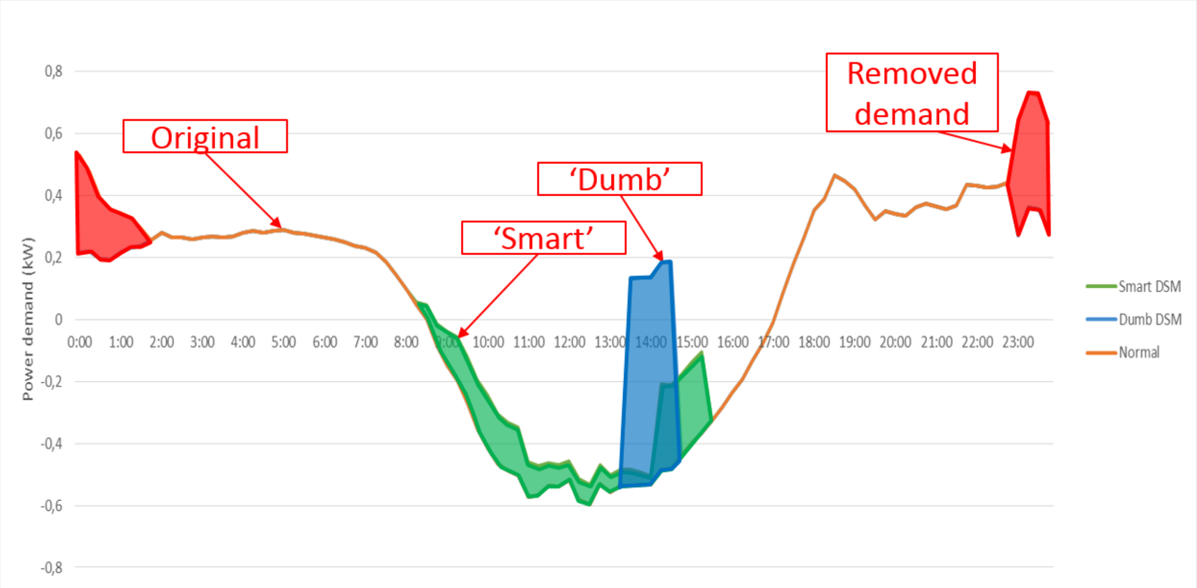


Figure 12: Effects of 'Dumb' and 'Smart' DSM on the original average yearly demand profile.

Figure 12 shows that both DSM types remove the original hot water production in the evening (between 23:00 and 2:00) and reschedule it in the middle of the day. The dumb DSM in figure 12 is started at 13:15, which result in a clear high peak at this time. The Smart DSM starts at a specific solar electricity overproduction, which differs over the year. Therefore, the average demand profile over the year is much more spread out over the day. In the summer months there are days were the set minimal overproduction of solar electricity is already reached around 8:00, while in the winter months this might only be around noon. There is also a evident peak in the Smart DSM profile due to the forced start time, which is in figure 12 set on 14:15. This is necessary to make sure there is hot water production on days which do not reach the minimal solar electricity overproduction. For both types this results in a reduction in the amount of electricity which is returned to the grid. This amount can be maximized by adjusting the start time for Dumb DSM and adjusting the solar electricity overproduction threshold and the forced start time of hot water production. It is important to note that this depends on the specific solar panel orientation of the home, as that orientation is directly related to the production profile over the day. The results here are for the Southeast orientations in Rijswijk. The results of the two types of DSM will separately be discussed.

6.2.1 Results Dumb DSM

The solar irradiance is the highest around noon during the whole year. Therefore, it is intuitive to put the start time of the Dumb DSM on around this time. However, it is interesting to note what the effect of Dumb DSM would be if the start time would be placed outside the noon hours. Therefore, the increase in self-consumption is calculated for a wide range of start times (on a 15-minute interval basis). The results are shown in figure 13.

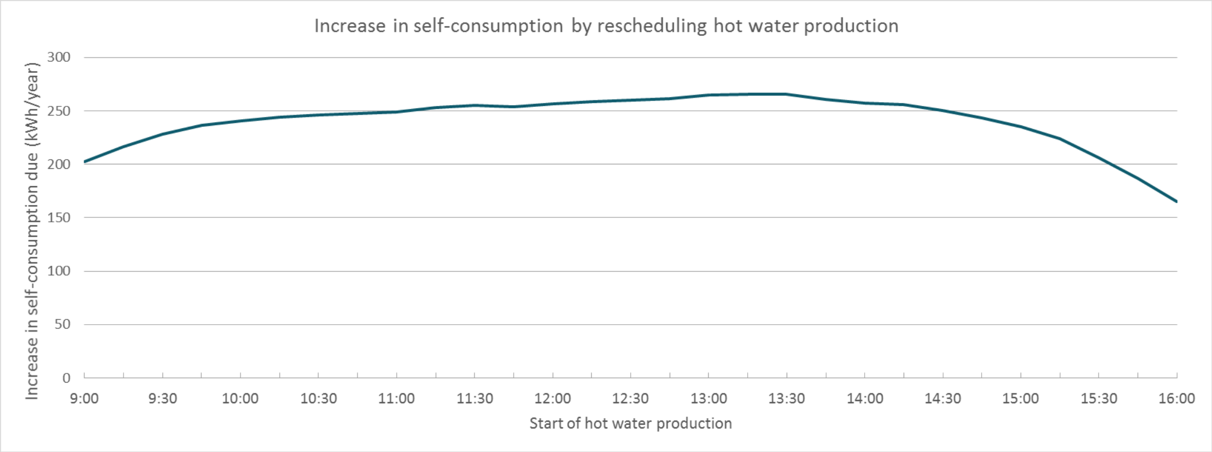


Figure 13: Increase in self-consumption due to Dumb DSM for different start times.

Figure 13 indicates two important results from the Dumb DSM analysis. The first one is that, as previously mentioned, the maximum self-consumption increase is indeed around noon, to be more precisely, if the DSM is started at 13:15. The second important result is that there seems to be only a very small effect on the increase in self-consumption for the different start hours. Putting the Dumb DSM start time between 9:45 and 15:00 all renders an increase in self-consumption of 240 kWh or higher, while the maximum is 265 kWh. This means that shifting the start time up to 3 hours and 30 minutes earlier or almost 2 hours later, it only reduces the self-consumption potential with 9%. This indicates that the specific start time of the DSM does not have a large impact on the self-consumption potential as long as it starts in the second half of the morning or the first half of the afternoon.

The maximum potential for self-consumption for Dumb DSM for this household is 265 kWh per year, which is 10% of the overproduced electricity . This can be implemented easily by adjusting the start timer of the hot water production manually, which could be done at a routine check of the equipment. Therefore, there is no costs for this options assumed. The 265 kWh per year more self-consumption do represent a financial gain if there is a form of net metering adjustments, which are displayed in table 13.

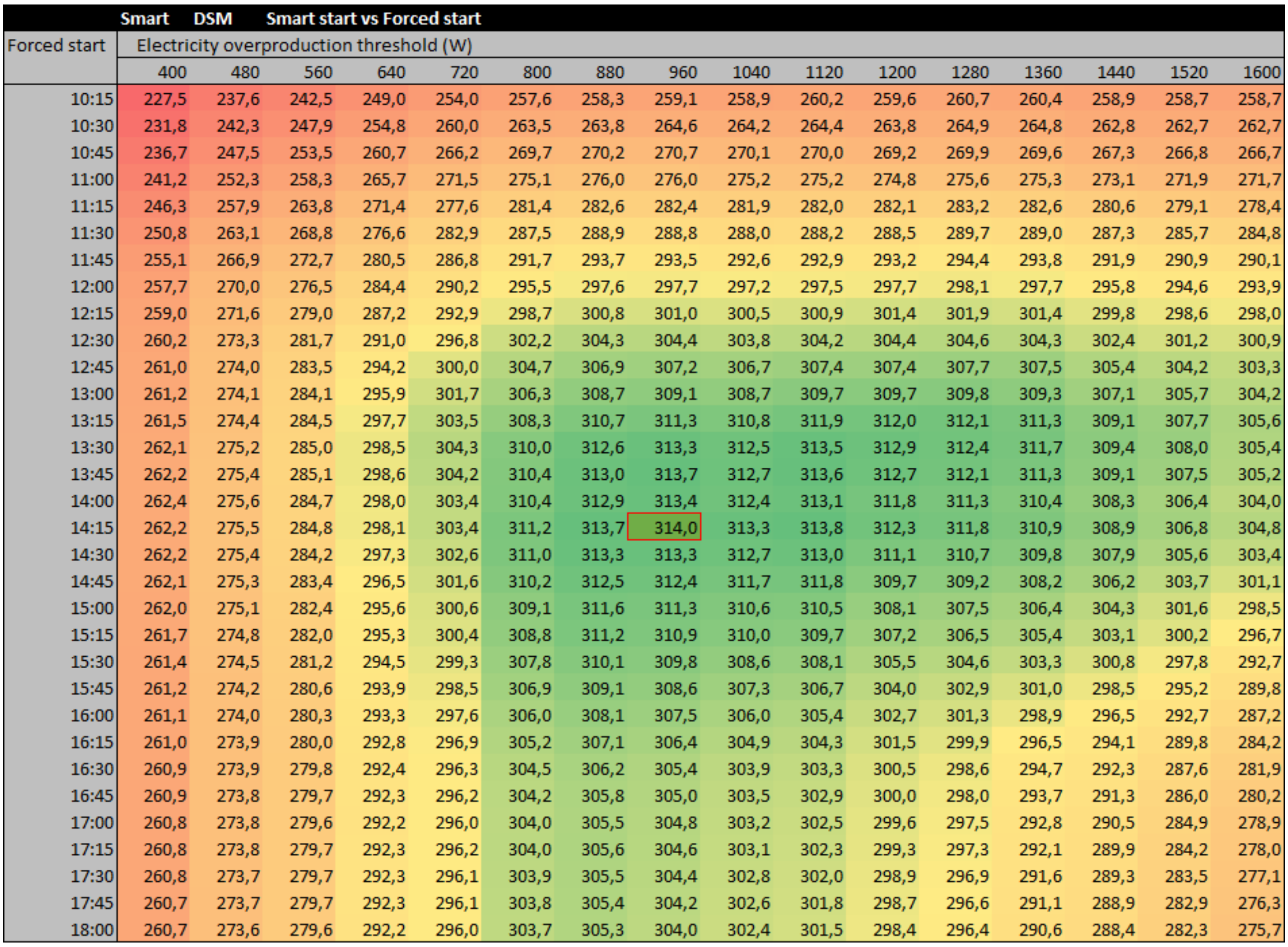
Table 13: Financial effects of increasing self-consumption with 265 kWh due to Dumb DSM.
NPV for 30 years with 5% discount rate.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 823	€ 518
	High increase	€ 1.157	€ 851

6.2.2 Results Smart DSM

While Dumb DSM has only one input variable, the start time, Smart DSM requires two input variables. These are the solar electricity overproduction threshold and the forced start time. The solar electricity threshold should not be too high as it won't start the hot water production at days where this threshold is not reached. It also should not be put too low, as it will start the hot water production while there is not yet 'enough' solar electricity overproduction. The force time start should not be put too early, as it will start hot water production while there is higher overproduction later on the day, but also not too early, as it might not use a significant amount of solar overproduction later on the day if the solar electricity overproduction threshold is not reached. Therefore, an optimum should be found between the threshold and the forced start time. This optimum is found by calculating the increase in self-consumption by adjusting these two input variables. The results of this calculation is found in table 14.

Table 14: Increase in self-consumption for different solar electricity production thresholds and forced start times.



	Smart DSM Smart start vs Forced start															
Forced start	Electricity overproduction threshold (W)															
	400	480	560	640	720	800	880	960	1040	1120	1200	1280	1360	1440	1520	1600
10:15	227,5	237,6	242,5	249,0	254,0	257,6	258,3	259,1	258,9	260,2	259,6	260,7	260,4	258,9	258,7	258,7
10:30	231,8	242,3	247,9	254,8	260,0	263,5	263,8	264,6	264,2	264,4	263,8	264,9	264,8	262,8	262,7	262,7
10:45	236,7	247,5	253,5	260,7	266,2	269,7	270,2	270,7	270,1	270,0	269,2	269,9	269,6	267,3	266,8	266,7
11:00	241,2	252,3	258,3	265,7	271,5	275,1	276,0	276,0	275,2	275,2	274,8	275,6	275,3	273,1	271,9	271,7
11:15	246,3	257,9	263,8	271,4	277,6	281,4	282,6	282,4	281,9	282,0	282,1	283,2	282,6	280,6	279,1	278,4
11:30	250,8	263,1	268,8	276,6	282,9	287,5	288,9	288,8	288,0	288,2	288,5	289,7	289,0	287,3	285,7	284,8
11:45	255,1	266,9	272,7	280,5	286,8	291,7	293,7	293,5	292,6	292,9	293,2	294,4	293,8	291,9	290,9	290,1
12:00	257,7	270,0	276,5	284,4	290,2	295,5	297,6	297,7	297,2	297,5	297,7	298,1	297,7	295,8	294,6	293,9
12:15	259,0	271,6	279,0	287,2	292,9	298,7	300,8	301,0	300,5	300,9	301,4	301,9	301,4	299,8	298,6	298,0
12:30	260,2	273,3	281,7	291,0	296,8	302,2	304,3	304,4	303,8	304,2	304,4	304,6	304,3	302,4	301,2	300,9
12:45	261,0	274,0	283,5	294,2	300,0	304,7	306,9	307,2	306,7	307,4	307,4	307,7	307,5	305,4	304,2	303,3
13:00	261,2	274,1	284,1	295,9	301,7	306,3	308,7	309,1	308,7	309,7	309,7	309,8	309,3	307,1	305,7	304,2
13:15	261,5	274,4	284,5	297,7	303,5	308,3	310,7	311,3	310,8	311,9	312,0	312,1	311,3	309,1	307,7	305,6
13:30	262,1	275,2	285,0	298,5	304,3	310,0	312,6	313,3	312,5	313,5	312,9	312,4	311,7	309,4	308,0	305,4
13:45	262,2	275,4	285,1	298,6	304,2	310,4	313,0	313,7	312,7	313,6	312,7	312,1	311,3	309,1	307,5	305,2
14:00	262,4	275,6	284,7	298,0	303,4	310,4	312,9	313,4	312,4	313,1	311,8	311,3	310,4	308,3	306,4	304,0
14:15	262,2	275,5	284,8	298,1	303,4	311,2	313,7	314,0	313,3	313,8	312,3	311,8	310,9	308,9	306,8	304,8
14:30	262,2	275,4	284,2	297,3	302,6	311,0	313,3	313,3	312,7	313,0	311,1	310,7	309,8	307,9	305,6	303,4
14:45	262,1	275,3	283,4	296,5	301,6	310,2	312,5	312,4	311,7	311,8	309,7	309,2	308,2	306,2	303,7	301,1
15:00	262,0	275,1	282,4	295,6	300,6	309,1	311,6	311,3	310,6	310,5	308,1	307,5	306,4	304,3	301,6	298,5
15:15	261,7	274,8	282,0	295,3	300,4	308,8	311,2	310,9	310,0	309,7	307,2	306,5	305,4	303,1	300,2	296,7
15:30	261,4	274,5	281,2	294,5	299,3	307,8	310,1	309,8	308,6	308,1	305,5	304,6	303,3	300,8	297,8	292,7
15:45	261,2	274,2	280,6	293,9	298,5	306,9	309,1	308,6	307,3	306,7	304,0	302,9	301,0	298,5	295,2	289,8
16:00	261,1	274,0	280,3	293,3	297,6	306,0	308,1	307,5	306,0	305,4	302,7	301,3	298,9	296,5	292,7	287,2
16:15	261,0	273,9	280,0	292,8	296,9	305,2	307,1	306,4	304,9	304,3	301,5	299,9	296,5	294,1	289,8	284,2
16:30	260,9	273,9	279,8	292,4	296,3	304,5	306,2	305,4	303,9	303,3	300,5	298,6	294,7	292,3	287,6	281,9
16:45	260,9	273,8	279,7	292,3	296,2	304,2	305,8	305,0	303,5	302,9	300,0	298,0	293,7	291,3	286,0	280,2
17:00	260,8	273,8	279,6	292,2	296,0	304,0	305,5	304,8	303,2	302,5	299,6	297,5	292,8	290,5	284,9	278,9
17:15	260,8	273,8	279,7	292,3	296,2	304,0	305,6	304,6	303,1	302,3	299,3	297,3	292,1	289,9	284,2	278,0
17:30	260,8	273,7	279,7	292,3	296,1	303,9	305,5	304,4	302,8	302,0	298,9	296,9	291,6	289,3	283,5	277,1
17:45	260,7	273,7	279,7	292,3	296,1	303,8	305,4	304,2	302,6	301,8	298,7	296,6	291,1	288,9	282,9	276,3
18:00	260,7	273,6	279,6	292,2	296,0	303,7	305,3	304,0	302,4	301,5	298,4	296,4	290,6	288,4	282,3	275,7

The results of table 14 are color coded for increased visibility, where red are the lower range of all the results and green is the higher range of all the results. The cell with the red borders shows the highest increase in self-consumption. From table 14 can be seen that there is a maximum when putting the solar electricity overproduction on 960 Watt and the forced start time at 14:15. However, the whole green area shows an increase in self-consumption of 300 kWh or more, which is only 5% lower than this maximum increase in self-consumption. This indicates that a large set of different input values can be used while maintaining the increase in self-consumption. There is a large set of combinations ranging between 720 W threshold and 1600 W threshold and between 12:15 forced start time and 17:30 forced start time which renders this 95% of the maximum increase in self-consumption. Therefore, the specific configuration of the Smart DSM does not have a large effect on the increase in self-consumption, if they stay within the previously mentioned boundaries.

The maximum potential for self-consumption for Smart DSM for this household is 314 kWh per year, which is 12% of the overproduced electricity. It is harder to implement compared to Dumb DSM due to the need for a connection between the smart meter and the heat pump, as well as some form of steering software which keeps track of the overproduction threshold and forced start time and starts the hot water production accordingly. It is hard to estimate what the costs will be for such a system, and therefore this research will calculated what the financial gain is when applying Smart DSM over Dumb DSM. If the installation costs of Smart DSM is higher than this financial gain, Dumb DSM is more cost efficient to apply. The financial gains from Smart DSM are displayed in table 15.

Table 15: Financial effects of increasing self-consumption with 314 kWh due to Smart DSM.
NPV for 30 years with 5% discount rate.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 975	€ 613
	High increase	€ 1.371	€ 1.009

6.2.3 Dumb DSM and Smart DSM comparison

The difference between the Dumb and Smart DSM is the amount of increase in self-consumption which these types are able to generate. The Dumb DSM renders 265 kWh more self-consumption, while the smart DSM renders 314 kWh self-consumption increase. The financial gains increased per scenario are displayed in table 16.

Table 16: Financial gains by applying Smart DSM over Dumb DSM without considering investment costs.
NPV for 30 years with 5% discount rate.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 152	€ 96
	High increase	€ 214	€ 157

These results can be visualized in a same method as figure 11 to show the relative effect of Dumb DSM and the incremental effect of Smart DSM over Dumb DSM on the NPV for the ZNE/buildings. This is done in figure 14.

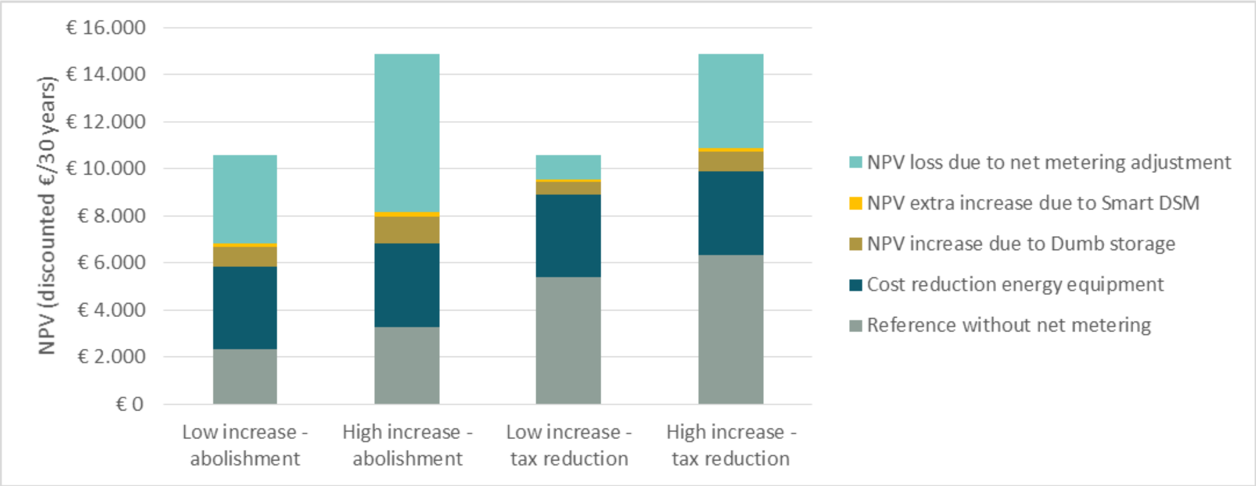


Figure 14: NPV breakdown of adjustments in net metering including DSM
Breakdown is similar to figure 7, while NPV improvements of Dumb DSM and Smart DSM are added.

If the investment costs stay below the values displayed in table 16, applying Smart DSM is more cost efficient than applying dumb DSM. In figure 14 it is easy to see that the incremental NPV of Smart DSM over Dumb DSM is However, it seems unlikely that such a system will be able to be produced, installed and maintained for under 200 euro and therefore it seems like Dumb DSM is the most cost efficient DSM type for these kind of ZNE-buildings.

6.3 Differentiated solar panel orientation

The third and last option to increase self-consumption which will be reviewed in this research is differentiating the orientation of solar panels.

6.3.1 Constructing solar profile from irradiance data

The panels on the ZNE houses in RijswijkBuiten are oriented in a southeast orientation, while other orientations might induce more self-consumption. Based on solar irradiance data for Rijswijk solar electricity production profiles were constructed for the original orientation as well as for three new orientations: southwest 38 degree inclination and east/west orientations with 10 and 30 degrees inclination. The constructed production profile of the initial orientation was validated against the profile of the smart meter data, which can be seen in figure 15.

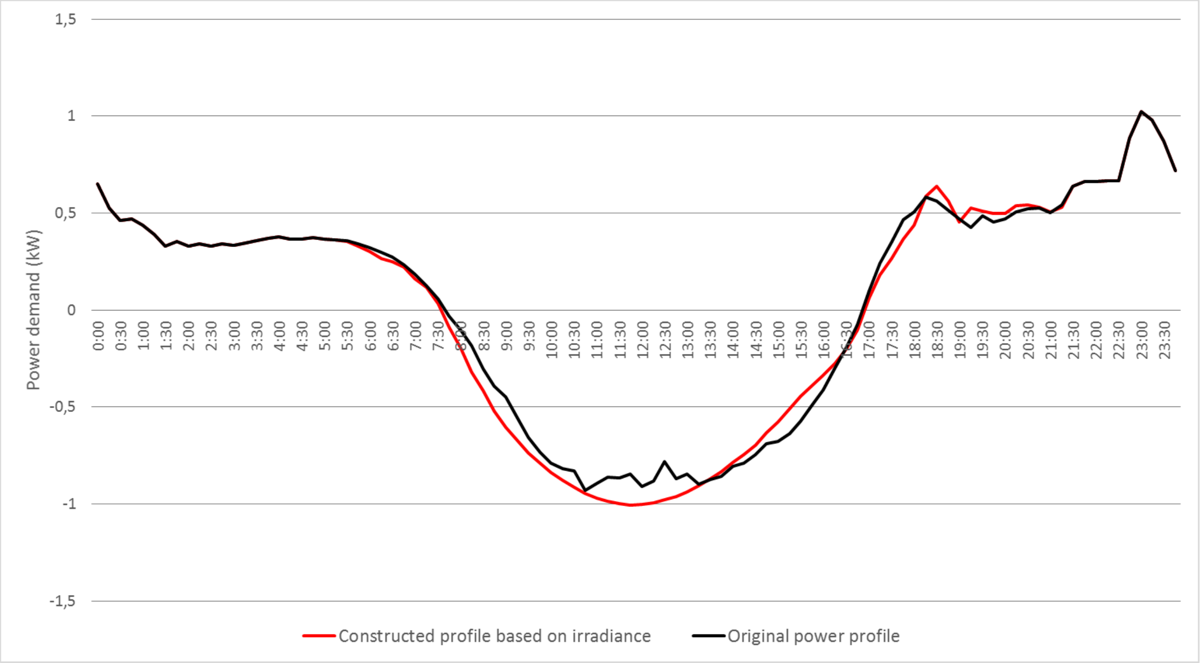


Figure 15: Constructed demand profile based on current solar panel orientation.

Figure 15 shows that the constructed profile and the original profile do not perfectly align. This is logical, as the constructed profile uses average irradiance profiles of the past years, while the original power profile is only based on one year of data. The two lines do share a very similar pattern and can thus be used to show an approximation of the potential of other orientations.

6.3.2 Effects of different solar orientations

The same profiles as in 6.3.1 are constructed for the other solar panel orientations. The profiles for all orientations are displayed in figure 16.

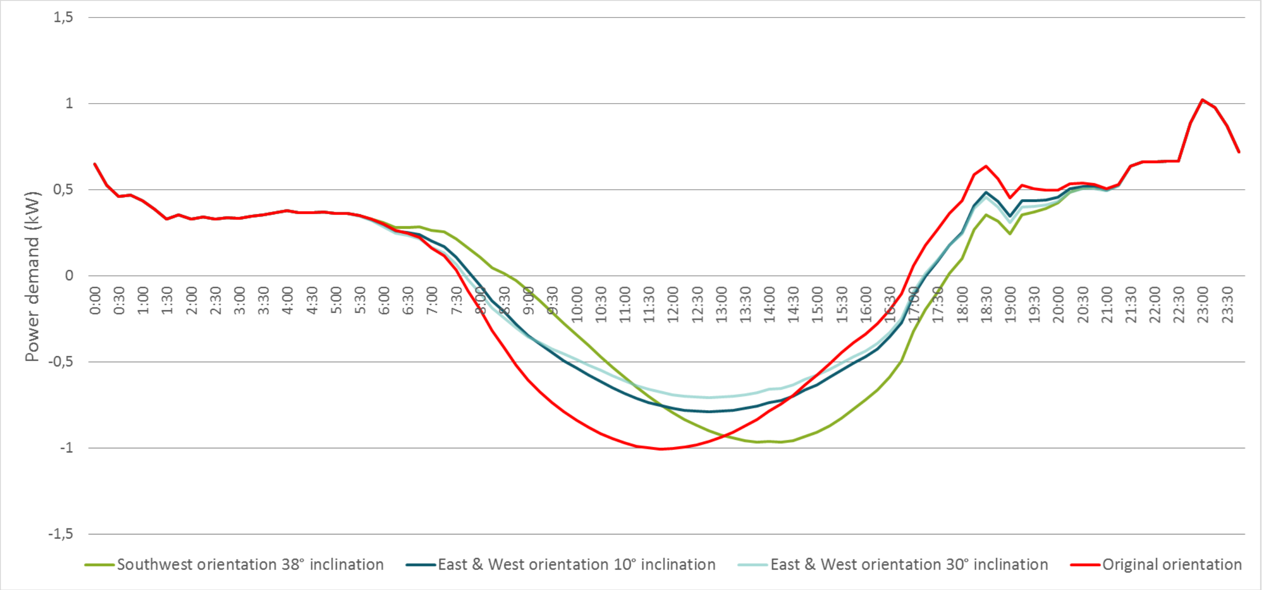


Figure 16: New constructed demand profiles based on different solar panel orientations.

The effects of the different orientations can easily be seen from figure 16. Southwest orientation gives more or less the same profile as the original orientation, except for the production being shifted to later in the day. This results in more self-consumption in the evening, where among other things cooking requirements increase the consumption profile compared to the middle of the day. Both east/west orientations renders a profile which seems to be in between the original and the southwest orientation, but resulting in less production over the day. Compared to the original orientation they have increased self-consumption later in the afternoon and early evening, while not relinquishing as much self-consumption as the southwest orientation in the morning.

6.3.2 Different solar energetic and financial benefits

It is important to weigh the increase in self-consumption against the loss in production, so these two outcomes have to be accounted for. The loss in production, amount of electricity less returned to the grid due to different orientation and the consequent increase in self-consumption are displayed in table 17.

Table 17: Production loss, electricity less returned to the grid and increase in self-consumption for different solar panel orientations compared to the original panel orientation.

	Southwest 38°	East/west 10°	East/west 30°
Production loss	-45 kWh	-274 kWh	-383 kWh
Less returned to the grid	159 kWh	353 kWh	498 kWh
Increase in self-consumption	114 kWh	79 kWh	115 kWh

Table 17 shows interesting differences between the orientations. From the three orientations, east/west 30° inclination shows the highest increase in self-consumption, but only 1 kWh higher compared to the southwest 38° inclination. However, the latter has much less production loss and is therefore more profitable. The east/west 10° inclination has both higher production loss and less increase in self-consumption compared to southeast 38° orientation. As Southwest is within this research clearly the best option, this main body of this research will only review the financial benefits of the southwest 38° orientation. The net financial benefits of the increase in self-consumption and production loss for southwest orientation are shown in table 18.

Table 18: Financial gains for panels on southeast with 38° inclination compared to original orientation.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 314	€ 131
	High increase	€ 442	€ 258

The results in table 18 show a positive NPV result for a southwest solar panel orientation compared to the current orientation, even in a scenario with tax reduction. However, compared to the other options, storage and DSM, the increase in NPV value is quite limited and does not significantly reduce the NPV loss due to net metering adjustments, which can be seen in figure 17.

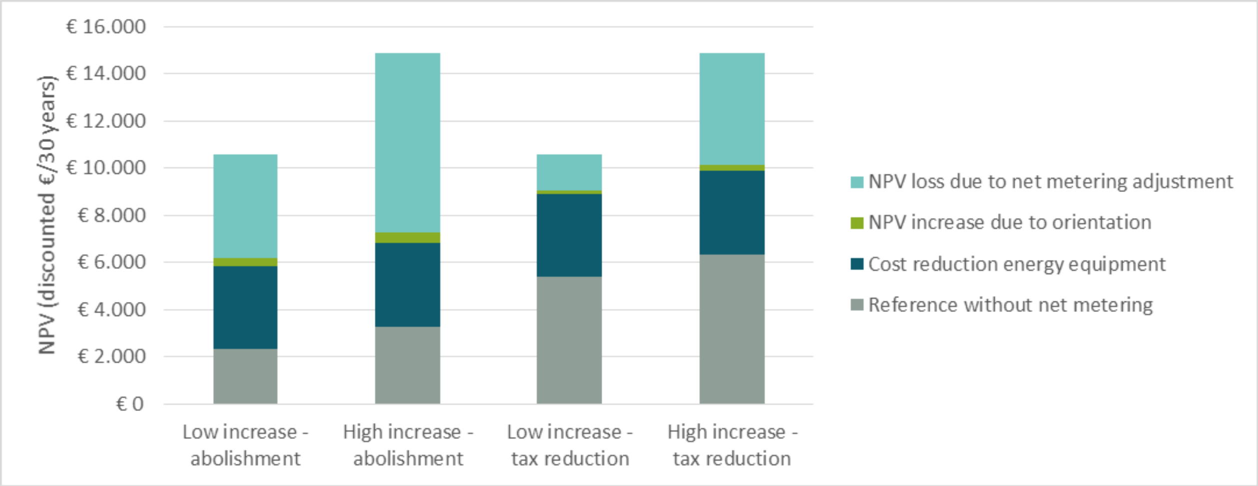


Figure 17: NPV breakdown of adjustments in net metering including southwest 38° orientation
Breakdown is similar to figure 7, while NPV improvements of orientation (green) is added.

Figure 17 shows that the effect of different orientation of solar panels is quite limited compared to the total loss of NPV due to net metering adjustments. This effect does not include any extra investments costs for a differentiated orientation. But requiring newly built homes to be orient their roofs toward the southwest does highly limited the building process of a new district, as all houses have a limitation in orientation. As the NPV value of this option is limited, the effects on the designing of new building projects are not justified. Therefore, this option will not be considered as viable for reducing the effect of net metering adjustments. The results of the east/west orientations are displayed in appendix E.

6.4 Interaction effects

The results of the previous mentioned technological solutions are all calculated independent from each other. However, applying multiple solutions at the same time will result in interaction effects. Demand Side Management and differentiated solar panel orientation will result in a new kind of power profile for the household, which induces a different battery storage potential.

6.4.1 Interaction effects between DSM and storage

The previously mentioned solutions of DSM and storage both seem to result in a financial gain for households in case of a net metering adjustment and to obtain the total result of the both solutions, it is important to investigate the interaction effects of the two technologies. Dumb DSM seem to be the best option from both types of DSM, as is yields very little adjustments to the current situation while having significant effect on the self-consumption. To obtain the interaction effect, first Dumb DSM is applied to the power profile of the households after which the storage algorithm is applied. If there is less electricity stored, there is also a reduction in electricity lost in storage. The net result of these two (electricity less stored minus electricity less lost due to less storage) is displayed in figure 18.

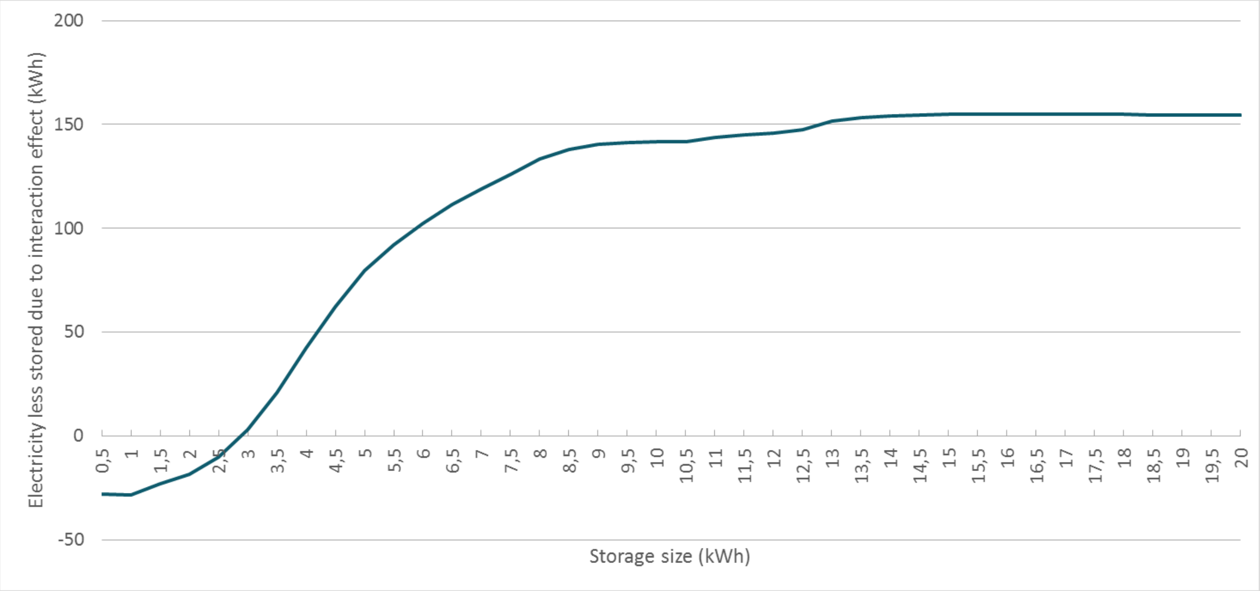


Figure 18: Less electricity stored due to interaction effect with DSM

Figure 18 shows that initially there is a negative amount of electricity less stored, which indicates more storage. This is due to the fact that at small battery sizes the battery reaches is maximum capacity very early in the day and does not take up any electricity for the rest of the day until there is some net demand. DSM renders net demand, especially in the winter months and thereby increases the amount of electricity stored for small battery sizes. For larger sizes this effect does not play a role and the interaction effect with DSM reduces the total amount of electricity stored.

6.4.2 NPV adjustment due to interaction effect

As Dumb DSM is the easiest and fastest option to apply, the (negative) interaction effects of applying both Dumb DSM and storage will be deducted from the potential of storage. This is based on the idea that Dumb DSM will be applied in any case and storage will only be applied if it still yields a positive result after DSM is already applied. The financial effect of the amount of electricity less stored can be calculated with an NPV calculations similarly to the NPV calculations before, except for the results of this NPV calculation is negative as it reduces the financial gain on applying storage. The results of this analysis are shown in table 19.

Table 19: Reduced NPV of storage due to interaction effect with DSM at optimal storage size.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 309	€ 57
	High increase	€ 502	€ 342

Table 19 shows that there is a significant reduction in NPV for storage in the different scenarios. However, in all cases there persists an positive NPV after deduction of the interaction effects. These NPV values for storage including the interaction effects with DSM are displayed in table 20.

Table 20: Recalculated NPV values for storage including the interaction effect with DSM.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 1.459	€ 32
	High increase	€ 2.883	€ 1.243

6.5 NPV gap of ZNE-building with Dumb DSM and storage

The results from storage (table 12) can be added up to the results from Dumb DSM to obtain the total result of applying both DSM and storage to a ZNE-building. Subtracting the effects of less equipment costs for solar panels and the heat pump, and the effects of Dumb DSM and storage from the initial NVP gap (which was calculated in section 5.5), the total effect for ZNE-buildings in 2020 can be calculated. This is done in table 21.

Table 21: NPV loss due to net metering adjustments when applying both DSM and storage.

Result	Low increase - abolishment	High increase - abolishment	Low increase - tax reduction	High increase - tax reduction
NPV loss due to net metering adjustment	€ 2.425	€ 4.005	€ 1.102	€ 2.896

The results from table 21 show that in all scenario's there is still a reasonable gap, ranging up to 4.000 euro NPV. This amount will be of significant impact on the applicability of the concept, as it gets a worse financial outlook. The total effect of all different components resulting in this net NPV loss are displayed in figure 19.

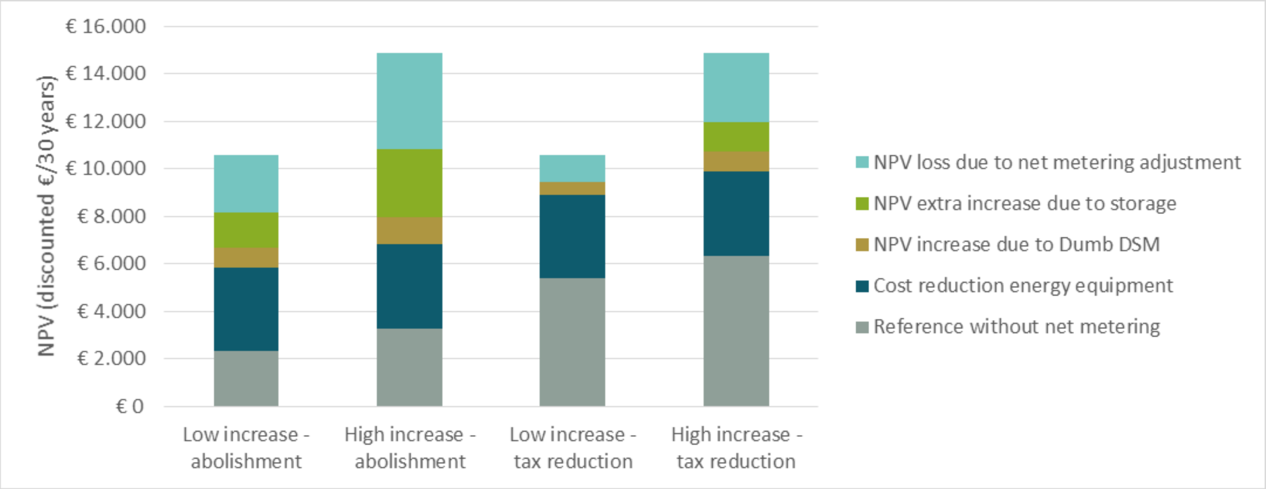


Figure 19: NPV breakdown of adjustments in net metering including DSM and storage
Breakdown is similar to figure 7, while NPV improvements of storage (green) and DSM (brown) are added.

The graph in figure 19 shows that a large part of the gap is filled due to the cost reduction of energy equipment. It will be of utmost important for the concept that current cost reduction trends will continue, otherwise the concept will have an even larger NPV gap in 2020. DSM has a limited effect on reducing the NPV gap, but is easy to implement and does not require investments. The potential of storage is very dependent on the specific scenario, where the low price increase with tax reduction scenario has a negligible NPV increase for storage, while in the high increase with abolishment scenario storage has a large effect on reducing the NPV gap.

7. Discussion

This research aimed to answer the research question with very specific and high resolution data. The high resolution 15-minute interval data resulted in outcomes which should properly reflect the real life case. However, there are several limitations to this research which should be discussed.

The analysis was done on one specific type of ZNE-buildings which were built in RijswijkBuiten in 2013. These households use heat pumps and solar panels, but do not provide the sole solution to obtain a ZNE-building. It is important to note that other ZNE-concepts can have very different profiles throughout the day and year. The analysis itself was based on two buildings, as there was only high resolution data available from these buildings. The building which the results are based on, was in energy use and production very similar to three other ZNE-buildings and it is therefore assumed that it does also apply to the other ZNE-buildings of this type with the same characteristics. However, each building will always have its own demand profile due to differences between inhabitants. The optimization is therefore for one specific house and not for all ZNE-buildings. But it does provide profound insight into the relative effects of adjustments in net metering and technological solutions.

Assumptions of price scenarios, net metering adjustments and storage efficiency are of major importance to the results discussed in this research. As can be seen by the differences in the different price scenarios, a higher or lower increase over time has a high impact on the NPV gap that arises to net metering adjustment. The specific adjustment regulation has also a major impact on the NPV gap, while the storage efficiency has a large impact on the potential of storage. The scenarios and values were chosen in a way to best reflect the market circumstances and due to the multiple scenario approach the effect of different values is showed.

This research tried to review the three most obtainable technological solutions to confront the NPV gap due to net metering adjustments. For storage and DSM this could be done with the high resolution data, while the differentiated solar panel results had to be done using a much lower resolution using average irradiance per month. Therefore, the resolution of the results is also much lower and it is recommended to review this part more in depth. For houses with a flat roof there is much less restriction to the building process than for houses with tilted roofs, so this option could be interesting for other houses than the ZNE-building this research focused on. It is also important to note that the production losses for east/west orientation can quite easily be confronted by placing an extra solar panel on the roof. As the investments in inverter and installation are already necessary for the other panels, placing an extra panel is not very costly.

One of the major improvements to the NPV gap is the cost reduction in energy related equipment, especially in the solar panels. As discussed in the results, some experts debate whether the cost reduction of solar panels will continue based on the previous years, as this was mainly due to module price reduction, while cost reductions on labor and other equipment is much lower. If this is true, the NPV gap in 2020 might be larger due to a lower cost reduction here. However, it is likely that the cost reduction of the heat pump is conservatively estimated because of the lack of data. It is possible that with increased penetration the heat pumps will also have an increased pace in cost reduction and will be cheaper in 2020 than estimated in this research.

The analysis for storage was only done on a separate storage medium built within the home. Other possibilities which are often mentioned are using the electric vehicle as storage medium or using one centralized district storage instead of individual batteries. The drawbacks to the former are discussed in the results, were mainly the absence of the car during overproduction will strongly reduce the storage capacity. There are some projects running on the latter, such as the district storage system of DSO Enexis in Etten-Leur. District storage has the advantage of more efficiently using the available storage space. However, current regulation does not provide for the possibility to net meter with electricity stored outside the house. District storage could be an interesting option, but it is necessary for regulations to change to be able to implement such a system after adjustments in the net metering regulation.

The last point of discussion is the double role of government within this specific problem. On the one hand they want to stop net metering to increase incentives to stop using the grid as free storage device and to reduce the loss of tax income. On the other hand they are pushing for more renewable energy and energy savings in the residential sector. It is very important for the government to not force the adjustment in net metering to obtain their former needs just to shut down ZNE-concepts financially which actively peruse the latter needs. The government should try to weigh different options and most of all stimulate the building of these kind of very efficient energy and producing buildings.

This research only reviewed two possible scenarios for adjustments in net metering regulation. It is important to review other options too, such as a limitation on the amount of kWh a house can net meter. Such an analysis would provide valuable insights into the effects of different net metering regulation adjustments on the competitiveness of ZNE houses. Besides further research into the effects of more different net metering regulation adjustments, it should also be reviewed to what extent the results of this research apply to normal buildings with a large array of solar panels. It is important for different environmental goals to stimulate the application of solar panels, but the possible adjustments in net metering will have an important effect on the large scale implementation of solar panels in the residential sector. Therefore, further research should be conducted into the effects on other parts of the residential sector and to what extent the same problems and solutions as in this research apply to other parts of the current and future housing stock.

8. Conclusions

This research has focused on the effects of adjustments of the net metering regulation and its effects on the business case of ZNE-buildings such as in RijswijkBuiten. More specifically, it has aimed to provide insight into the Net Present Value (NPV) changes for this building concept as well as the potential softening effect of technological solutions on this change in NPV. ZNE-buildings in RijswijkBuiten were analyzed for this purpose, which were built with extensive isolation, a heat pump and a large array of solar panels. The current concept is more or less cost neutral and uses the net metering regulation to return about 2650 kWh per year back to the grid. Adjustments in net metering will result in a negative financial balance for these types of buildings. This research looked into the effects on this concept in the year 2020, as this is the first year the net metering could be adjusted.

The first part of this research (section 5) focused on the financial effects for the ZNE-concept. Energy related equipment is likely to decrease in price in the coming years, which was calculated to be 3525 euro lower in 2020 compared to current investment costs. This development on itself causes a better business case for this ZNE-concept. However, the ministry of Economic Affairs stated that he would review the net metering regulation in 2017 and possibly adjust it in 2020. Two main possibilities for this adjustment are a total abolishment of the regulation or a fixed tax reduction replacing the current regulation. The NPV gap this generates depends on the development of the electricity price components. In order to analyze the effect of different price developments, two scenarios were used: i) a ‘low increase’ scenario in which the electricity price increases with 1% per year and ii) a ‘high increase’ scenario in which the electricity price increases with 3% per year. The low increase scenario with a fixed tax reduction results in the lowest gap (€5.177) in NPV compared to no adjustment in net metering, while the high increase scenario with total abolishment results in the highest (€11.570) NPV gap. Combined with the cost reduction of the energy related equipment of €3525, the gap is considerably lower, but still a significant negative effect on the business case of ZNE-buildings.

The second part of this research (section 6) focused on technological solutions to reduce this gap. The solutions reviewed are: electricity storage, Demand Side Management (DSM) and differentiating the solar panel orientation. For electricity storage a battery is the most interesting option which could be profitably applied under both net metering adjustment scenarios at a price of €212/kWh. Only in the low increase abolishment scenario there is a very low NPV increase for the concept, only €89. The other three scenarios provide between €1.585 and €3.385 NPV increase for the concept. The DSM solution would change the hot water production from the late evenings to the afternoon. A ‘Dumb’ variant would do this to a fixed time, improving the NPV with between €518 and €1.157 due to increased self-consumption of solar electricity. A ‘Smart’ variant would start the production based on solar electricity overproduction, but this would only provide for an extra increase in NPV of between €96 and €214 over the increase in the ‘Dumb’ variant. This does not include the investment costs, as these are hard to estimate. It is unlikely however that the extra investments and efforts justify the extra increase in NPV of the ‘Smart’ variant over the ‘Dumb’ variant. The last technological solution is differentiating the solar panel orientation to provide for a production that better matches the consumption profile. The current orientation of the ZNE-buildings solar panels is south-east by south, but orienting the panels towards the southwest or half east and half west would result in a lower total production, but a better match between production and consumption. From the three orientations, the southwest orientation is the most interesting one, as it combines low production loss with relatively high increase in self-consumption. For the different scenarios this would result in an NPV increase of €131 to €442. This does require severe restrictions on the building process, as it requires all homes built with roofs facing southwest. As the NPV increase of this solutions is low compared to the other solutions, it is concluded that this NPV increase does not justify the building restrictions.

All scenarios show a considerable gap in NPV compared to a situation where net metering regulation was maintained. The best strategy to reduce this gap is to apply a battery with Dumb DSM. This will cause interaction effects, as the DSM will cause the demand profile to change, reducing the total amount of kWh which can be stored yearly. The interaction effect of DSM reduces the NPV improvement potential of storage with between €57 and €502. The NVP gap left after taking into account cost reduction, storage and DSM is between €1.102 and €2.896 for the tax reduction scenario with low and high price increase respectively. The gap left for the abolishment scenario is €2.425 and €4.005 for the low and high price scenario respectively. The largest reduction of the gap is due to the cost reduction of the energy related equipment, while the technological solutions result in a smaller but also significantly reduction of the NPV gap.

This research showed that a large gap in NPV will arise in different net metering adjustment and price development scenarios. About two thirds of this gap can be confronted by cost reduction and technological options. The remaining one thirds of this gap will reduce the competitiveness of ZNE buildings compared to normal buildings. The ZNE concept has various advantages over regular houses, such as more efficient energy use and more electricity production. To not quell this kind of concept, the government should carefully weigh the effects of adjusting the net metering regulation, taking into account that ZNE houses can help to achieve goals on energy efficiency and renewable production.

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Appendix A

The storage potential of batteries was calculated by running a storage algorithm over the dataset. The dataset consists of two arrays of data, one of the electricity taken from the grid, one array for the electricity which is taken from the grid (referred to as 'From Grid') and one array for the electricity which is returned to the grid (referred to as 'To Grid'). This means that electricity which is directly consumed within the homes and does not enter or exit the house is not present within the data. This electricity is referred to as 'directly consumed electricity'. The storage potential is only based on the electricity To Grid and From Grid, as a storage technology will reduce the electricity To Grid by storing it and reducing the electricity From Grid by providing the electricity at a later time.

However, as the time steps of the data source are 15 minutes, there is a reasonable amount of time steps were both electricity is taken from the grid and electricity is returned to the grid within 15 minutes. For the storage algorithm, this research uses the net interaction with the grid called 'Net Exchange', defined as the net electricity imported from the grid as a positive number and net electricity exported to the grid as a negative number. Equation A.1 displays the calculation of Net Exchange.

$$For\ each\ time\ step\ t: \qquad Net\ Exchange\ (t) = From\ Grid(t) - To\ Grid(t) \tag{A.1}$$

From this Net Exchange, the battery potential can be calculated by adding surplus electricity (which is a negative Net Exchange) to a storage variable for each time step, while removing electricity from the storage variable in case of production shortage. This variable will be referred to as the variable 'Stored' and the algorithm used is displayed in equation A.2.

$$Stored\ (t+1) = Stored\ (t) - Net\ Exchange\ (t) * \eta;\ MAX(Capacity);\ MIN(0) \tag{A.2}$$

Where η is the round-trip efficiency and the variable stored cannot exceed the nominal storage capacity 'Capacity' and cannot be lower than zero. It is assumed that the storage device is installed empty, therefore Stored (t = 0) = 0. The total stored electricity over the year then becomes the summation of increase in the stored variable over the year (which has 35040 15-minute time steps), displayed in equation A.3.

$$Total\ Stored = \sum_{t=1}^{35040} (IF\ (Stored\ (t) - Stored\ (t-1)) > 0) \tag{A.3}$$

Appendix B

The DSM potential is calculated based on the data made available by TNO. An DSM algorithm for both types of DSM will be used to calculate the potential. For both the Dumb and Smart DSM option the algorithm will reduce household consumption between 23:00 (variable ‘$\text{start}_{\text{old}}$’) and 2:00 (variable ‘$\text{end}_{\text{old}}$’) with 1,2 kWh every day to simulate the change of hot water production away from the night. The Dumb DSM option algorithm then adds 1 kW of consumption for five consecutive 15-minute time steps (between variables $\text{start}_{\text{new}}$ and end_{new}) to add a total of 1,25 kWh of demand. This is 4% higher than the before mentioned 1,2 kWh, but cannot be adjusted to 1,2 kWh due to the 15-minute time steps without changing the fixed 1 kW demand. Each 15-minute time step will then contain 0,25 kWh of extra use (which equals 1 kW). The algorithm will produce a ‘DSM’ variable which includes both the added consumption in the middle of the day as positive values, while it insert the reduction after 23:00 as negative values. The Dumb DSM algorithm is shown in equation B.1.

Dumb DSM algorithm *(B.1)*

```
$For\ every\ day:$    $For\ start_{new} \leq\ t \leq end_{new}: DSM(t) = 0{,}25$
                      $For\ start_{old} \leq\ t \leq end_{old}:$
                          $IF\ Net\ Exchange(t) \geq 0{,}25: DSM(t) = 0{,}25$
                          $ELSE: DSM(t) = Net\ Exchange\ (t)$
```

The Smart DSM algorithm is essentially the same as the Dumb DSM algorithm, except for the possibility to start before the set time based on solar electricity production. The Smart DSM algorithm will wait for a certain solar electricity threshold to be reached before starting the hot water production. If this point is not reached by the set time, the hot water production is forced to start (the $\text{Start}_{\text{forced}}$ variable). The Smart DSM algorithm is shown in equation B.2.

Smart DSM algorithm *(B.2)*

```
$For\ every\ day:$    $For\ t < start_{forced}\ \&\ Started = NO\ :$
                          $IF\ Net\ Exchange\ (t) > threshold:$
                              $Started = YES$
                              $For\ DSM\ (t)\ to\ DSM\ (t+4):$
                                  $DSM\ (t) = 0{,}25$
                      $If\ t = start_{forced}\ \&\ Started = NO:$
                              $For\ DSM\ (t)\ to\ DSM\ (t+4):$
                                  $DSM\ (t) = 0{,}25$
                      $For\ start_{old} \leq\ t \leq end_{old}:$
                          $IF\ Net\ Exchange(t) \geq 0{,}25: DSM(t) = 0{,}25$
                          $ELSE: DSM(t) = Net\ Exchange\ (t)$
```

The DSM variable will be added to the Net Exchange variable. From this summation the total amount of electricity returned to the grid is recalculated, whereupon the difference is taken as the reduction in electricity returned to the grid, as displayed in equation B.3.

$$Reduction\ in\ electricity\ to\ grid = Original\ to\ grid - DSM\ to\ grid \tag{B.3}$$

Appendix C

Input data into the PVGIS system to obtain the solar irradiance data for RijswijkBuiten.

Table C: Solar irradiance input data in PVGIS (2015)

Dataset	Location	Rotation (0 = north, 90 = east)	Inclination (0 = horizontal)
Original orientation	Rijswijk	145 (South-east by south)	38 degrees
South-west orientation	Rijswijk	225 (South-west)	38 degrees
East 10 inclination	Rijswijk	90 (East)	10 degrees
West 10 inclination	Rijswijk	270 (West)	10 degrees
East 30 inclination	Rijswijk	90 (East)	30 degrees
West 30 inclination.	Rijswijk	270 (West)	30 degrees

Appendix D

The input variables which were used for the storage algorithm are shown in table D.

Table D: Input variables for storage algorithm

Variable	Value	Unit
Start year	2020	-
Lifetime	30	years
Battery size	0,5 to 20	kWh
Battery cost	212	€/kWh
O&M costs battery	0	%
Maximum cycles	3000	# of cycles
Maximum lifetime	10	years
Efficiency	86	%
Electricity price 2015	0,2207	€ in 2015
Market price in 2015	0,0489	€ in 2015
Electricity price increase	1 OR 3	%
Market price increase	1 OR 3	%
Discount rate	5	%/year
Average overproduced electricity	2650	kWh/year

Appendix E

The results of the east/west orientations are shown in table E.1 and E.2

Table E.1: NCW of production loss and more self-consumed electricity of east/west 10° inclination.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 3	€ -404
	High increase	€ 4	€ -403

Table E.2: NCW of production loss and more self-consumed electricity of east/west 30° inclination.

		Net metering adjustment	
		Abolishment	Fixed tax reduction
Price increase	Low increase	€ 19	€ -556
	High increase	€ 26	€ -548