DEVELOPMENT OF A SOLAR STRATEGY FOR HELSINGBORGSHEM

An analysis of Solar irradiation, Life Cycle Costing, Life Cycle Assessment and Integration of Photovoltaics on Roofs in Helsingborg

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Master thesis in Energy-efficient and Environmental Buildings
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Lund University

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This degree project is the final part of the master program leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

As of this moment humankind's total energy use consists of 87% of non-renewable energy sources. The government of Sweden is aiming for 100% renewable energy system by the year of 2040. The city of Helsingborg is experiencing a solar panel expansion, the installed power increased with 139% from 2015 to 2016.

The overall aim of this master thesis was to create a solar strategy for the municipality owned real-estate company called Helsingborgshem. This strategy included a solar mapping of their soon to be renovated buildings, Life Cycle Costing, a gate-to-gate Life Cycle Assessment analysis and integration of photovoltaics. A solar map was created alongside with the categorization list taking into account the average solar irradiation of the studied roofs and the possibility of a solar system installation on the investigated buildings from a building permit point of view. Three buildings from different areas were picked out for a deeper investigation, where additional information was added in the 3D-modeling. Thereafter, the complete Photovoltaics system was designed and several cases were conducted. From the estimated hourly electricity usage data, three cases were considered, - the current case was based on the requirement of which facilities' energy usage could be covered by Photovoltaics. Two other cases were assumed according to the future building renovation plans. An analysis of a battery implementation was performed for one of the investigated buildings but it was proven as not worth the investment due to the currently high price together with the need of a replacement after 15 years. Four different panels from China and Poland were compared and investigated for a Life Cycle Cost analysis and the most profitable result was established. In total 24 cases were considered for each of the three buildings. The result showed that the Chinese panel, Seraphim 320 W, have a higher total savings alongside with the shortest payback time. The result of the gate-to-gate Life Cycle Assessment showed the environmental impacts per kg panel of the transportation emissions from producer to end customer was 53 times smaller when transported from Poland in comparison to China. From a Life Cycle Assessment point of view and integration, the Polish panels were recommended for the implementation.

Acknowledgments

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Abbreviations/Glossary

AC	– Alternating Current
AIM	– Angle Incidence Modifier - the difference in the energy output due to the change in the angle of the sun towards the solar panel;
BBR	– The Swedish Building Regulations - rules and general recommendations;
BEN	– Building Energy consumption at Normal usage;
CEC	– California Energy Commission;
CO2	– Carbon Dioxide;
DC	– Direct Current;
GHG	– Greenhouse Gas - compounds which are able to trap heat in the atmosphere and are the main cause of the greenhouse effect;
LCA	– Life Cycle Assessment - the tool for assessing the environmental impacts from products;
LCC	– Life Cycle Costing - the tool for calculating the total cost and savings of the project which takes into account the time period, interest rate, value of money and price growth rates;
NPV	– Net Present Value - the approach to evaluate the profitability of the investments;
Primary energy	– Energy production directly from the source;
PV	– Photovoltaics;
SEK	– Swedish Crowns;
STC	– Standard Test Conditions - solar panel output test conditions which are used by most producers.

1 Introduction

Due to the exponential growth of population and increasing demand on energy, the growth of energy use is expected to be 40% by 2035. Right now humankind's total energy use consists of 87% of non-renewable energy sources; this must be changed due to the CO2 and other Greenhouse Gas emissions (World energy council, 2016). There has to be a readjustment for a sustainable energy sector to be able to meet the goals that were adopted in the Paris Agreement in 2015 (Baylan & Lövin, 2016). The government of Sweden has set up a goal for reaching 100% renewable energy system by the year of 2040.

The sun can provide the annual amount of energy the whole world needs in one hour (Munari Probst, et al., 2012). More and more companies as well as private individuals are applying photovoltaic systems on their properties. With the continuous expansion of solar energy, there is a possibility of the continued price drop of PV panels (Solar energy industries assosiation, 2017). Currently the city of Helsingborg is experiencing a solar panel expansion, the installed power increased with 139% from 2015 to 2016 (Solisyd, 2017). In all Helsingborg there are 116 solar energy systems which can annually produce 2 745 900 kWh.

Nowadays, most solar systems are designed to meet the technical requirements and little attention in the development process is given to the architectural perspective. For a solar system being called as integrated it must be properly replaced by the elements of the building envelope and also keep the architectural view (Munari Probst, et al., 2012).

1.1 Helsingborgshem

Helsingborgshem is a non-profit real estate company owned by the city of Helsingborg. It was founded in 1946 and has since then continuously developed and expanded. By having 12 000 rental apartments, it was the biggest housing company in Helsingborg by the moment when the study for the thesis was completed. The company has ambitious goals to decrease the energy use of their buildings and to expand their usage of renewable energy. Now Helsingborgshem is facing a new challenge in regards to the EU Directive 2020 by designing energy-efficient housing and are therefore implementing PV-systems on the roofs of their properties to lower their primary energy demand. Currently Helsingborgshem owns seven solar systems and an additional ten solar systems will be installed during 2017 on their new built buildings. Right now their solar systems together have 235 kWp installed.

Due to the upcoming renovations within five to ten years of approximately 90 buildings in their building stock, the company is interested in developing a solar strategy - designing and calculating the PV capacities and performing life cycle cost analysis. The foundation of this thesis was the request from Helsingborgshem to cover only the electricity they pay for themselves by the means of PV. This electricity usage includes elevators, elevator management rooms, general lighting in staircases and corridors, exterior lighting, basement lighting and facilities, common laundry room and ventilation fans. It does not include the electricity use of the tenants, which all have their own electricity meters and pay for their own usage.

1.2 Future usage of PVs for Helsingborgshem

The government of Sweden has an aim for 100% renewable electricity production by the year of 2040 (Regeringskansliet, 2016). From this, solar produced electricity should be 5-10% (Energimyndigheten, 2016). The government has assigned the Swedish Energy Agency responsible for analyzing how to reach this aim. There has been a growing number of solar installations in Sweden recent years, with a 60% increase in 2015. To reach the previous mentioned aim, several measures have been taken, including lowering the solar tax on the own consumed solar electricity with 98%, from 0.292 SEK/kWh to 0.005 SEK/kWh, which will be valid from the 1st of June 2017. For Helsingborgshem, this decision meant that they could move forward with their plans of expanding their solar electricity production on their roofs. The government has also increased the subsidy by eight times since the start of the subsidy in 2009. In total, 50 million Swedish Crowns have been placed for this subsidy annually till 2019.

The overproduced electricity is sold back to the grid for 0.40 SEK/kWh, which is approximately 40% of what the bought electricity costs. Furthermore, a micro production of solar energy could apply for a tax return on their sold electricity, equalling 0.60 SEK/kWh, although this amount is limited by 18 000 SEK annually. Since Helsingborgshem already have many smaller solar facilities, they do not apply for this tax return, hence all the systems are registered to the same organisation number.

There is an insecurity for Helsinborgshem when installing solar panels on an already existing building, because they need a permit from the building department. Therefore, a thorough research in combination with a dialog with the municipality at an early stage is recommended.

1.3 Aim and Objectives

The aim of this thesis was to focus on investigating the possibility of producing solar electricity on the roofs of the buildings owned by Helsingborgshem and to perform an LCC and LCA analysis of PVs and integrated PV systems.

The objectives of this thesis can be defined as:

- To provide a complete list of the result of the average amount of solar irradiation on the roofs in combination with a list providing information if the roof is suitable for the implementation of PVs on the buildings owned by Helsingborgshem and are soon to be renovated;

- To study the implementation of solar panels on the roof of buildings, from an integration point of view;

- To perform a Life Cycle Cost analysis for various future cases and different system designs;

- To study which environmental impacts are caused by PV panels and to conduct a Life Cycle Assessment for transportation from production site to end costumer (gate-to-gate).

1.4 Limitations

The irradiation study was based on the 3D map made by laser measurements taken from the sky which was provided by the municipality and could have a marginal difference in size compared with the actual buildings.

The solar irradiation was based on the average annual irradiation of the whole roof for the investigated buildings. Therefore, an individual shading analysis should be performed in some cases, which was not made in this study.

The interest rate, price growth rates for electricity, PVs and inverters were taken from the statistics and have constant values during the whole period of this study.

Within the scope of this thesis the prices of the roof materials were not included in the LCC analysis.

Hourly data for the energy use was calculated according to the equipment loads and estimated schedules, hourly data was applied only for one day during the weekend and one day during the week each month.

Future energy use of the buildings was applied according to two estimated future cases since the company does not have a renovation plan for the buildings.

The LCA was only conducted within the scope of transportation from the manufacturer to the end customer (gate-to-gate) due to documents not being provided regarding LCA from the manufacturers.

The study did not take into account technical and construction integration of the panels due to the planned renovation.

1.5 Contributions

Between the authors most work has been performed and discussed equally. The work was divided at one point where Alina focused on the LCC while Julia worked on the LCA.

2 Theoretical background

This chapter contains an overview of the available PV technologies, system losses, PV integration and former LCA on PVs. Thereafter, a small introduction study of the difference in the studied manufacturing regions of the PVs and different transportation routes from China to Europe is presented.

2.1 Photovoltaics

The principal of photovoltaics is a direct conversion of light into electricity using semiconducting materials. Photovoltaic systems can be stand alone or connected to the grid. A photovoltaic system consists of various components such as solar cells, frame, glass, backing material, electrical connections and wirings, mechanical connections and mounting. Currently there are various types of photovoltaics presented on the market. Silicon is a leading technology in making solar cell but due to its high price, the constant research is mainly made about exploring the possibilities of increasing the efficiency of the solar cells produced by thin film technology. The types of materials used to produce solar cells can be seen in the Figure 2.1.

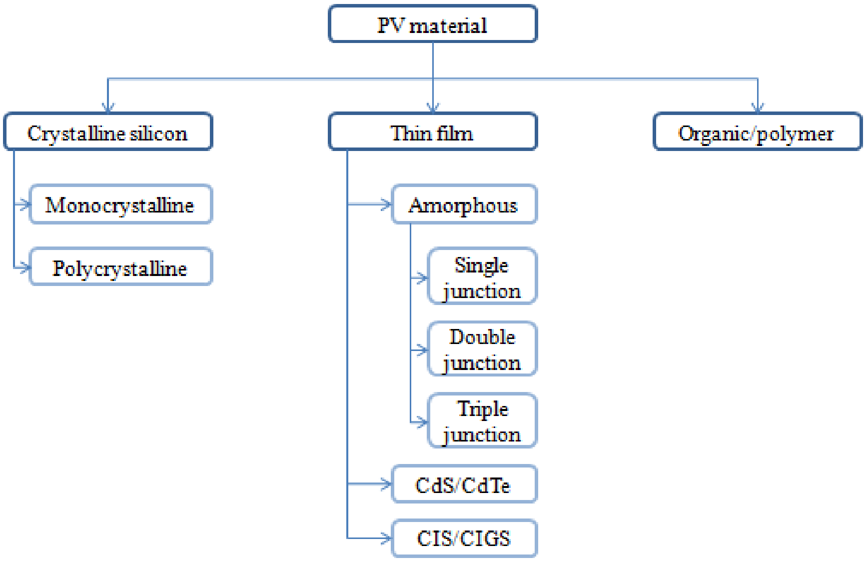

Figure 2.1: Solar cells types (Tyagi, Rahim, Rahim, & Selvaraj, 2013).

Nowadays, solar cells are mainly produced from the most abundant mineral in the Earth's crust - silicon dioxide. The silicon for the cells was for a long time used from the waste of semiconductors but due to the increased demand, the solar industry is using their own production plants for solar-grade silicon which is cheaper due to the lower restrictions about the purity of the silicon. Cells which are produced from pure silicon (monocrystalline) show the best performance but the price on the market is still relatively high (Tyagi, Rahim,

Rahim, & Selvaraj, 2013). A lot of research has been made in regards to lowering the price of the solar cells. One alternative to the single crystalline cell is so called polycrystalline cells which are produced from lot of small individual crystals instead of one large crystal which makes the material considerably cheaper although has proved less efficient (Breeze, 2005). According to the various resources and research, the efficiency of the monocrystalline silicon cell can reach more than 20% but the manufacturers normally claims 15% - 17%.

Thin film technology is less expensive compared to the silicon due to the less amount of material used and the smaller technology process. The solar cells and the contacts are distributed on the backing material. The thin film thickness needs to be a few micrometers so the advantage of the thin film solar cells is the lower consumption of materials and also bigger opportunities for design. The current known materials used are amorphous silicon, cadmium telluride (CdTe), cadmium sulphide (CdS), copper indium gallium selenide/copper indium selenide. Amorhous (uncrystallized) silicon is the most popular thin-film technology which have an efficiency of 5%-7% and double or triple junction design which can increase it up to 10% which is proned to a quick degradation (Paridaa, Iniyanb, & Goic, 2011). Cadmium telluride, due to the ability to give an ideal band-gap, high efficiency and stability could be efficiently used as a solar cell material but faces the environment related problem with telluride. Copper indium diselenide thin film technology has been considered promising due to suitable electronic and optical properties. Although laboratory-scaled tests showed up to 20%, the actual offers on the market have typical efficiencies of 12%-14% (SunShot, 2016).

The organic photovoltaics is an emerging technology which has a high potential on the market due to the increase in efficiency over time and potentially short payback period (Corazza, Krebs, & Gevorgyan, 2015). Organic solar cells have a potential to produce electricity widely available and accessible for those people which do not have a connection to the grid. Due to the fast manufacturing process and low payback time it is possible to make the price compete with the electricity produced by non-renewable sources and thus it is becoming potentially attractive for the market. The photovoltaic material can be produced from inexpensive organic semiconductors and can easily be recycled compare to the non-organic silicon cells. Organic photovoltaics have a lot of difficulties such as low lifetime and low efficiency to maximum 8% (Addin, 2011). In addition to this, other losses such as reflections, series resistance, inverters, wiring, connections, dirt, temperature and shading has to be considered.

Due to crystalline cells having the biggest share on the market, mono- and polycrystalline cells will be considered in this thesis.

2.2 System losses

While designing a solar system it is crucial to take into account all the possible losses which could affect the results dramatically. System losses are divided into irradiance, DC, AC and other losses.

Irradiance losses appear due to the tilt/orientation, shading, soiling, snow and incidence angle. Firstly, the tilt and orientation loss shows how much the tilt and orientation of the panel affects the output. The maximum radiation in Helsingborg can be achieved with 39° panel tilt towards South. Shading reduces the solar irradiation on a surface. In case of crystalline silicon cells this factor needs to be taken into consideration due to the great affect it has on the energy production (Hemmerle, Jakubetz, Weller, & Unnewerh, 2010). Shading can appear due to the neighboring buildings and vegetation; the parts of the building itself such as chimneys, roof windows and ventilation shafts; dirt, snow, leaves etc. The closer the shading object to the surface the greater is the blackout effect. The energy production can be cut by 60%-80% by the total shading (Hemmerle, Jakubetz, Weller, & Unnewerh, 2010). Apart from shading, there is a soiling loss which appears due to dirt, sand and other soiling. In Southern Sweden several studies were conducted in order to investigate the need of cleaning PVs and the loss due to the soiling. One study was performed for two PV panels in identical conditions, one of the panels was cleaned every day and another one was left untouched. The study period was one year and the results showed that the panel which was cleaned daily got only 1 % higher result (Solelprogrammet, 2017). Losses according to the snow coverage are also negligible in the Southern Sweden due to the quick melting. Due to the fact that incidence angle rarely happen to be 0, there are optical losses which occur due to increased reflection which have to be taken into account. For that, such factor as Angle Incidence Modifier (AIM) is included during the analysis of this study.

DC losses include environmental condition losses, nameplate rating, light-induced degradation, connections, mismatch and wiring. Environmental condition losses occur due to the fact that the panels do not operate at Standard Test Condition (STC) constantly during the year, consequently to this the temperature and irradiance conditions are fluctuating and the production is lower. Recommended value for the reduction factor according to California energy commission (CEC) is 0.89. Nameplate rating or “power tolerance” is the difference between the power value specified on the back of the panel and the actual number. This happens because of the STC which the panel was tested on and considering the fact that real conditions differ from the STC, a decrease or increase of power can occur. Nowadays most modern panels have a positive power tolerance. Light-induced degradation loss is considered as a fixed loss due to the change in electrical characteristic of the cell when being exposed to the sun. This happens only during the first several hours of the panel usage. Connections loss is an electrical resistance add due to the internal wiring connections inside the panel. Mismatch loss is manufacturing imperfections between two modules of the same type which leads to slightly different current-voltage characteristics. Wiring loss is a DC wiring between the panels which connect panels to the string, add resistance and thus lowers the power.

AC losses comprise inverter losses. The inverter in the PV system is used in order to convert DC from the panel to the AC used for the appliances. Inverter’s efficiency affects the output power from the panel and its efficiency can reach up to 96% in factory conditions, which in reality this factor can be lowered down to 82-92% (Endecon Engineering; Regional Economic Research, 2001). Other losses include age losses which occur overtime and caused by weathering of PV panels and system availability loss which is taken into account for such circumstances when energy is not available and system is offline due to maintenance.

2.3 PV integration & Design Strategies

Photovoltaic technologies could have an important part in the possibility of reducing the GHG emissions with the usage of solar energy for supplying electricity for buildings (Hemmerle, Jakubetz, Unnewerh, & Weller, 2010). The PVs nowadays are still not used commonly which is the outcome of legislation issues, architectural quality of the building which needs to be preserved and conventional thinking. Most solar systems today are designed to meet the technical requirements and little attention is given to the architectural perspective (Munari Probst, et al., 2012).

Three points of view of architecture should be taken into account while considering a solar system installation - Functionality, Construction and Aesthetics (Munari Probst, et al., 2012). For a successful integration of PV panels all the mentioned characteristics should be a part of the building design. Therefore, if a product has a certain amount of offered flexibility, the process of integration is easier to implement. For a solar system being called integrated, it must be properly replaced by the elements of the building envelope and also keep the architectural view. The development of new technologies on the PV market has made it possible to get solar panels in any shape and color which can be used together with common building materials, leading to making the integration process easier.

Some manufacturers of PVs provide non-active panels, which have the same appearance as the producing panel, in order to fulfill the envelope function and provide a complete uniformed coverage. With the usage of non-active panels, so called “dummies”, there is a possibility for the same aesthetic design even for those places where the solar exposure is low or non-existing (Munari Probst & Roecker, 2013).

The design strategies for building-mounted PVs have to be a symbiosis of the energy, architecture and construction (Hemmerle, Jakubetz, Unnewerh, & Weller, 2010), see figure 2.2. “It must be remembered that constructional and architectural integration are two fundamentally different things, which in the ideal case complement the energy concept to create a positive overall outcome” (Hemmerle, Jakubetz, Unnewerh, & Weller, 2010, p. 40)

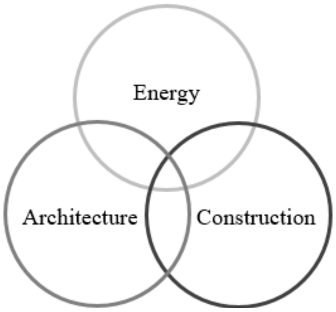

Figure 2.2: Design Strategy for building mounted PVs (Hemmerle, Jakubetz, Unnewerh, & Weller, 2010).

2.4 Life Cycle Assessment of PVs

This section contains information about previous LCAs on different kinds of PV panels and transportation alternatives from the shipping route between Europe and China.

2.4.1 Former Life Cycle Assessments and harmonization

Throughout the years many life cycle assessments on PV cells have been carried out. The National Renewable Energy Laboratory (NREL) conducted a harmonization project of these LCA of different kinds of photovoltaics. This was completed to help clarify, reduce the variabilities and inconsistencies. The result represented the outcome of 400 studies of PV systems. The PV systems reviewed included crystalline silicone (c-Si) containing monocrystalline and multicrystalline and thin film (TF) represented in amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) (NREL, 2012). The end result of this harmonization concluded that PV systems equal about 40 g CO_2 eq/kWh. Most of the emissions are released in the first stage of the whole systems life cycle, see Figure 2.3.

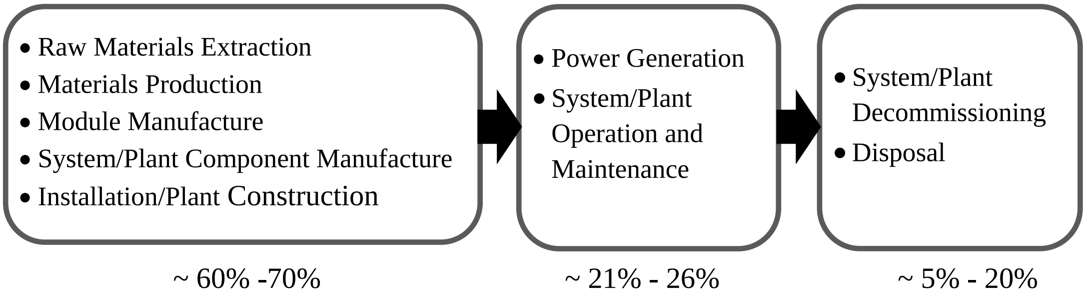

Figure 2.3: In percentage where the emissions accrues in the studied LCA cases. (NREL, 2012).

2.4.2 Comparison between production in China vs Europe

In a study, of monocrystalline silicon, multicrystalline silicon and ribbon silicon, the difference in LCA was investigated of manufactures in China compared to Europe (Yue, 2014). China is a leader in PV production with 62% worldwide while Europe shares only 10% of the total share. Therefore, the most manufacturing are located in China where there is a large difference in the industrialization as well as environmental restrictions compared to Europe, where most PV panels are later installed. The conducted study revealed that the PV panels produced in China consume 28-48% more primary energy in comparison to Europe.

2.4.3 Alternative transportation via Northern Sea Route

The most important sea route link between Asia to Europe is the Suez Canal Route, where 24.5% of the total global cargo transportation ships pass through. With the growing traffic through this passage a future case might lead to a long line of ships waiting for their turn to pass (Zhao, 2016). To avoid this future possibility of a vessel queue and an extensive waiting time, studies of finding new sea routes from Asia to Europe are of interest. Due to the global warming the Arctic sea ice has rapidly decreased over the last decades, therefore made it possible for an alternative path of the Northern Sea Route (NSR). There is a substantial length difference between the two paths, the route from Shanghai to Rotterdam is measured to about 14 600 km via NSR compared to the approximately 22 200 km via the Suez Canal. See Figure 2.4 for the two routes.

Figure 2.4: The route between Shanghai and Rotterdam via NSR and SCR (Zhao, 2016).

The investigation about NSP showed that due to the shorter distance fewer emissions are exposed to the atmosphere (Zhao, 2016).

3 Methodology

This chapter includes a detailed explanation and input data of all the steps that are performed in the process of this thesis. The flow chart of the process can be seen in the Figure 3.1. The fields with grey background point out the main parts of the thesis while white ones are auxiliary.

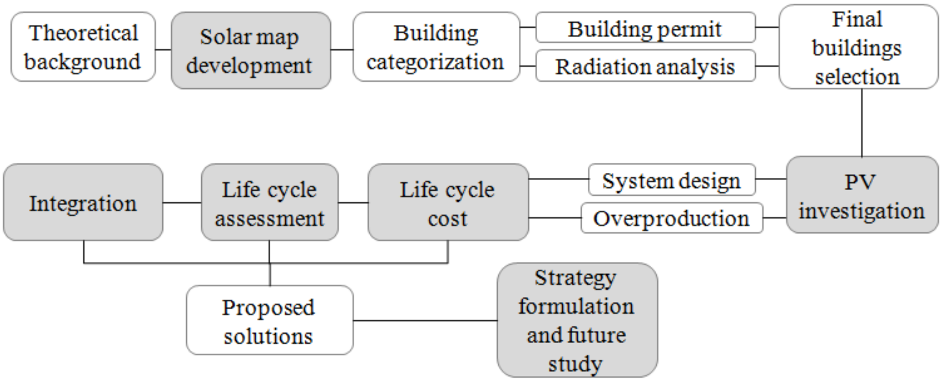

Figure 3.1: Flow chart of the thesis process.

3.1 Preface and initial meetings

A study of PV systems and building integrated PVs was accomplished in the beginning of the thesis, alongside with initial meetings and a fieldtrip to some of the existing PV installation that Helsingborgshem has. Another meeting was held with the municipality to discuss their progress with the ongoing project of the development of the solar map of Helsingborg and to get access to the 3D-models of the city.

3.2 Development of the solar radiation categorization list

The city of Helsingborg has a 3D-map of the whole municipality, latest updated in 2014. This map was used for this thesis in the process of the development of the solar potential map, simulated by using Rhinoceros 5 and DIVA (Robert McNeel & Associates, 2017). In order to import the file into Rhinoceros 5 a step in between was made by importing it to the software Sketch Up (Trible Inc., 2017) as surfaces instead of meshes, see Figure 3.2 for the flow chart of the detailed imported map. The original 3D-model did not have any digital elevation model or vegetation. Therefore, an estimated ground level was modelled in Rhinoceros 5. To simulate the possible shading and reflections from neighboring buildings, all building in the radius of 100 meters from the object were modeled. The simulated grid size on the roof was set to 0.5 · 0.5 m.

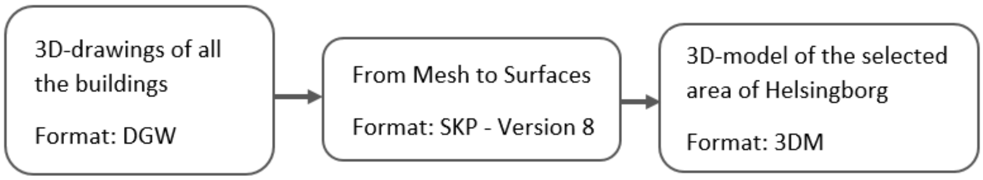

Figure 3.2: The detailed flow chart of the conversion of the 3D-map.

The simulated surfaces were named: Roof, Surroundings and Ground. The surfaces were then made into objects in Grasshopper with different material settings in DIVA. The materials were assumed to be Lambertian diffusers with a 35% reflectance for both the roof and the surrounding buildings and for the ground it was assumed to have a diffuse reflectance of 20%, similar to earlier studies (Jakubiec, 2013).

The next step consisted of running simulations of the buildings which were planned to be renovated during the next five to ten years. Thereafter, the first categorization list of the buildings according to the solar radiation quality performance was created. The initial values used for making the solar radiation list were based on the solar map of Lund which was based on a thesis project (Hedén, 2013). In order to get the right thresholds, the radiation levels were scaled to match the weather files maximum radiation, see Table 3.1. The maximum solar radiation for Helsingborg city was analyzed using DIVA 4 and resulted in 1 116 kWh/m² annually. The value used for Lund solar map was 1 170 kWh/m² annually, this difference could be explained by the difference in software used, different weather files and also due to the fact that Helsingborg is located slightly more North.

Table 3.1: The Categorisation system of Lund compared to Helsingborg.

Category	**Lower Limit for Lund** / (percentage of the maximum solar radiation in Lund)	**Lower Limit for Helsingborg** / (percentage of the maximum solar radiation in Helsingborg)	**Radiation** (kWh/m² and year)
Not suitable	0 %	0 %	< 800
Reasonable	68 %	72 %	800-900
Good	77 %	81 %	900-1020
Very Good	87 %	91 %	1020

3.3 The Solar map of Helsingborg

During the beginning of 2017, the city of Helsingborg created a solar map, accessible for anybody that wanted to find out how much solar radiation their specific roofs had in Helsingborg. The results of the radiation analysis made in DIVA 4 were compared to the existing solar map of Helsingborg. The solar map of Helsingborg was created in the ArcGIS software. ArcGIS is a geographic information system which is developed specifically for working with maps. Due to the difference in the calculation methods, the difference in grid size and the different ways of presenting information for the viewer, the results were not entirely similar and will not be discussed further in this report.

3.4 Development of the sensitivity categorization list

To understand if the roofs were suitable for the installation of a solar system seen from a legal perspective, an interview with a representative of the building permit department from the municipality of Helsingborg was conducted. To get the permission for an installation of a solar system, the municipality’s building permit department has to approve the application. A building permission is often not required for private housing, usually only an application is needed with specific information regarding the esthetics and mounting of the system and the technical information. For multifamily dwellings it is always necessary to apply for a building permit. In general, the municipality is positive towards PV or solar collectors’ installations unless the building has a cultural protection marking. All buildings in Helsingborg are registered in a database where the building might have a yellow or red mark or no cultural mark. The yellow mark indicates that the building belongs to the cultural memory category but still can be considered for solar energy installation. In case of the building having a red mark, the building belongs to the cultural heritage program and can hardly be negotiated for PV or solar collectors’ installations. The project must also prove to follow the fire departments recommendations (Lewis-Jonsson, 2017).

In regards to the municipality’s opinions and possibility of the PV installation, a list was created showing how plausible it was to get an approval from the municipality to mount a solar system. The list was based on the cultural protection system from the municipality, where three different levels of sensitivity were conducted: Likely, Possibly and Unlikely.

3.5 Safety for the fire department

PV panels are still producing electricity even if the main switch in the building is disconnected. This can cause problems for the firefighters in case of a fire. The system can carry up to 1000 Voltage which can lead to a lethal outcome for the emergency workers. There are a few measures that can be taken to make sure the emergency staff do not get injured and also lowers the possibility for fire. Firstly the system should have a Module Level Control which purpose is to cut the power to the solar panels no matter when and where the power is turned off. This will limit the current to a safe 1 Volt. Secondly there should be a manual switcher for emergencies placed on the inside of the door of the main exit door (Räddningstjänsten Skåne, 2016).

It is not recommended from the Safety Department of the North-west region of Skåne that the whole roof should be covered with solar panels. There should be a possibility for the firefighters to open up a hole for ventilation purposes through the roof construction. This possibility should be on both sides of the firewall and also across a fire section.

A solution with individual DC-switcher for the panels is the best and most safe according to the emergency workers. This solution is easier to apply to new solar systems and might be costly when installed on current systems (Räddningstjänsten Skåne, 2016).

3.6 Final categorization and case study of three buildings

After both categorisations were completed, the final list was made and several buildings with the highest radiation result, and likely to get an approval from the permit building department were selected. In total three typical case buildings were chosen in each area of Isbanan 1, Tapiren 1, Rosa 2. These buildings were considered for future investigation of PV implementation. Afterwards, a detailed radiation analysis was performed for the three buildings - Tyringegatan 292, Edwin Berlings gata 2 and Harlyckegatan 7, see Figure 3.3.

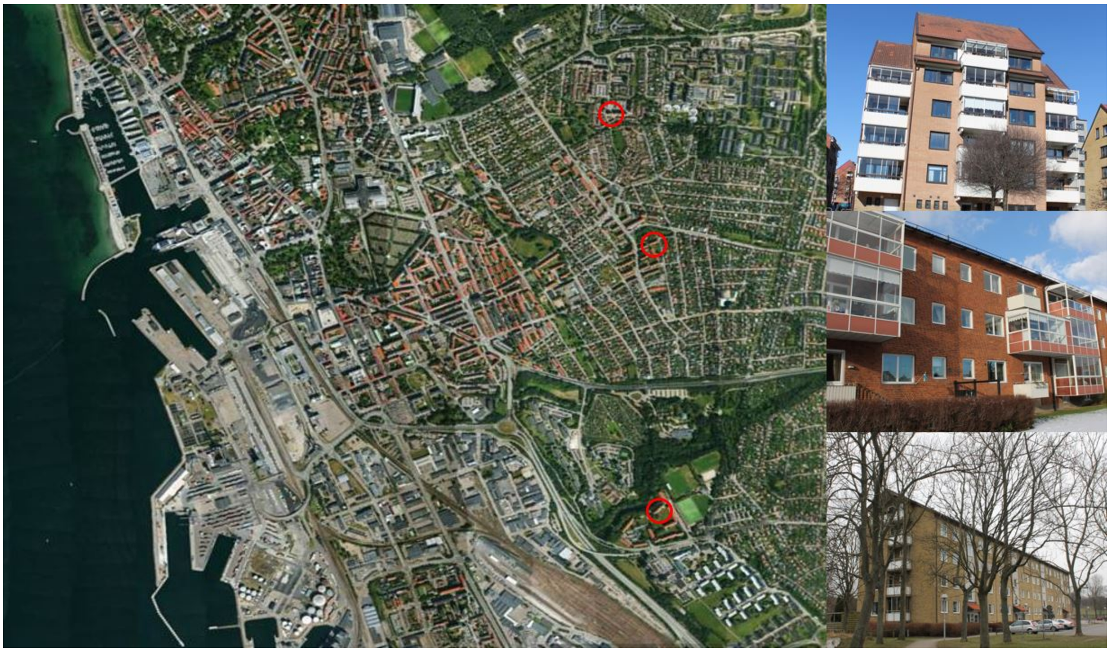

Figure 3.3: Map of Helsingborg with the three case buildings chosen for further investigation (from top to bottom - Tyringegatan 292, Edwin Berlingsgata 2, Harlyckegatan 7).

The detailed radiation analysis included shading from chimneys and vegetation, neighbour buildings' facades, windows, window frames and balconies. The reflectances of the building materials used in the detailed simulations were based on measurements performed with a luminance meter and a NCS color measuring device. Thereafter, a list of the materials was made using the result as input in the online tool on the website called Colour Picker for Radiance, see Table 3.2. The website provided a radiance material code that was used for the DIVA's material file and implemented into the Grasshopper script (JALOXA, 2017).

Table 3.2: The reflectances of the materials used for the detailed simulations.

Material	**Reflectance / %**
Yellow brick facade	46.3
White metal balconies and window frame	82.2
Dark brick facade	11.1
Orange metal facade and balconies	36.7
Cream coloured brick facade	71.8
Red brick facade	16.2
Red balconies and details	26.7
Dark window frame and doors	6.6

3.7 PV system design

This chapter represents regulations in regards to solar energy, the estimated hourly electricity usage data of the buildings including several future cases due to the planned renovation of the buildings. The PV sizing for the studied modules, considered system losses and overproduction are also included in this chapter.

3.7.1 Regulation regarding energy usage and energy declaration

A building’s energy usage can be divided into two parts. The part this thesis considers was the building’s facility energy, meaning the electricity the building needs to fulfill its requirements, for example the electricity for pumps and fans. This applies for equipment placed in or around the building. Electrical appliances used for other purposes than for the building, such as engine heaters and garden lights, are not a part of the buildings facility energy and are therefore not a part of the buildings specific energy consumption. The other part can be named household or plug loads, the energy used by the tenants.

The building’s specific energy consumption could be reduced with the energy produced from solar panels, according to Building Energy consumption at Normal usage (BEN). Solar produced electricity can only be used for the energy posts within the building’s facility energy use. If the solar produced energy is used for household and operational energy, this should not be taken into consideration when making the buildings energy declaration (Boverket, 2016). The building’s technical equipment for heating, cooling, ventilation, hot water, lighting and electricity, is allowed to be covered by solar, wind, ground, air or water produced electricity on or around the property, see Table 3.3.

Table 3.3: Energy usage of electricity that are allowed to be covered by solar, wind, ground, air or water produced electricity (Boverket, 2016).

Energy use	**Included in the building's specific energy use**	
	Yes	**No**
Equipment		
Electricity for appliances such as dishwasher, washing machine, dryer (also in the common laundry room), stove, refrigerator, freezer, and other household appliances, computer, printer, TVs and other electronics, tools etc.		X
Electricity for tools, machinery, manufacturing processes, etc. used for professional use		X
Electricity for elevator	X	
Electricity for server room, computer central or similar		X
Charging pole for electrical car		X
Heating and cooling		
Floor heating, towel dryer, or other device in wet rooms intended for heating	X	
Towel dryer or other appliance in wet rooms (not heated floors, according to BBR 16) with another primary purpose other than heating (e.g. drying a towel) and where the room has another heater for heating or a centrally located one, without the cooling surfaces against cooler areas or to the free		X
Infrared heat on the balcony, covered balcony, loggia, terrace or patio installed v tenants or consumers		X
Motor heater		X
Heating cables in the gutters, downspouts and storm drains in roofs or terraces, designed to prevent ice formation	X	
Electric heating as cold draft protection	X	
Heating cable in the ground, intended for melting snow, frost protection for wires or similar		X
Power for pool		X
Power for sauna		X
Heating for ventilation and cooling for activity outside of regular operating hours		X
Cooling for server rooms, computer centre, exercise room, laboratory, restaurant kitchens, coolers or similar		X

Energy use	**Included in the building's specific energy use**	
Appliances that are located outside the building but intends to support the building, e.g. pumps and fans for free cooling	X	
Hot water		
Domestic hot water according to typical values of BEN	X	
Domestic hot water in addition to typical values of BEN		X
Ventilation		
Electricity for fans for the basic ventilation for residential, commercial, restaurants, exercise rooms, garages, laboratories	X	
Electric energy as a result of forced ventilation	X	
Forcing the cooker hood. Increased electricity to the fan at forcing the cooker hood in connection cooking or other activity. Increased electrical energy for other activities that are temporary		X
Electricity for fans of restaurant kitchens		X
Fume cupboards, work bench in laboratories (which are not included in the basic ventilation)		X
Lighting		
Exterior lighting intended to illuminate the building facade, entrances or the space under the larger canopies (even if the light source is placed at a distance from the building)	X	
Exterior lighting on the building facade at entrances to individual rooms or apartments, and their balconies, patios, terraces, etc.		X
Exterior lighting which function is to illuminate the area around the building, but within the property (garden lighting)		X
Interior lighting in residential apartments, local apartments, cellular offices, open plan offices, meeting rooms etc.		X
Indoor lighting in common areas such as stairwells, elevator, basement laundry and storage	X	

3.7.2 Hourly electricity usage data

In order to size the system and also calculate the overproduction from the PV system for conducting a LCC analysis, hourly data was assessed. For that, the information regarding the building equipment's loads was collected and a schedule was estimated. Different profiles for the three case buildings for each month and also for a weekday and weekends were created. The equipment included in the calculation can be seen in the Table 3.3.

Table 3.4: The equipment included in the calculation of the hourly data.

1	Ventilation exhaust fan
2	Laundry rooms, drying rooms, mangle
3	Electricity for laundry rooms, drying rooms, mangle
4	Elevators
5	Exterior lighting
6	Staircase lighting
7	Basement, attic, electricity and elevator rooms lighting
8	Lighting in the storage rooms, garages
9	Timers for laundry, exterior lighting, entrance lock

Constant energy use was estimated for the exhaust fan of the building; the schedule for laundry rooms was applied depending on the building's schedule; elevators, staircase lighting was applied depending on the most occupied hours, i.e. early mornings (7.00-8.00) and evenings (17.00-19.00). Exterior lighting schedule was designed according to the daylight hours. Lighting in the attic, basement, facility rooms, storages and garages was calculated according to the occupancy usage. The graphs which represent the hourly data for typical winter and summer weekday and weekend (12th of January, 14th of January, 13th of July, 16th of July) for the investigated cases can be seen in the Figures 3.4 – 3.6. The data was created according to the calendar of 2017. Detailed graphs with the data for all the months can be seen in Appendix B.

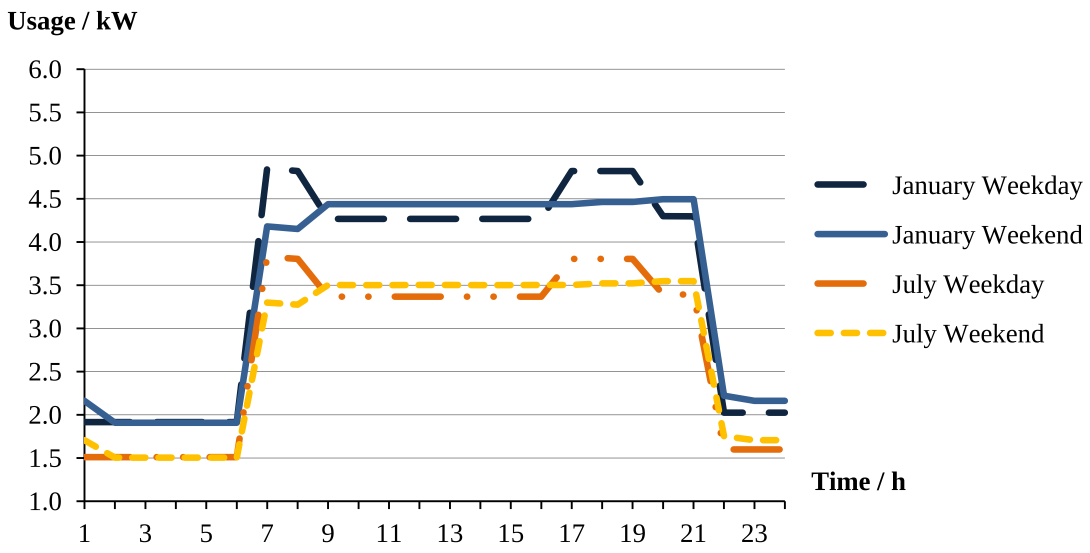

Figure 3.4: Tyringegatan 292 estimated hourly electricity usage.

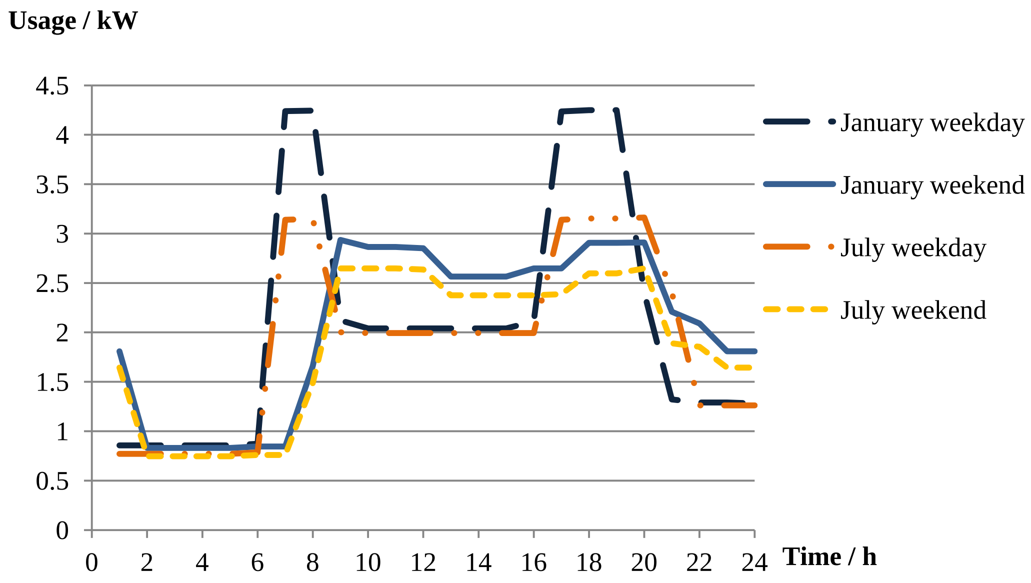

Figure 3.5: Edwin Berlings gata 2 estimated hourly electricity usage.

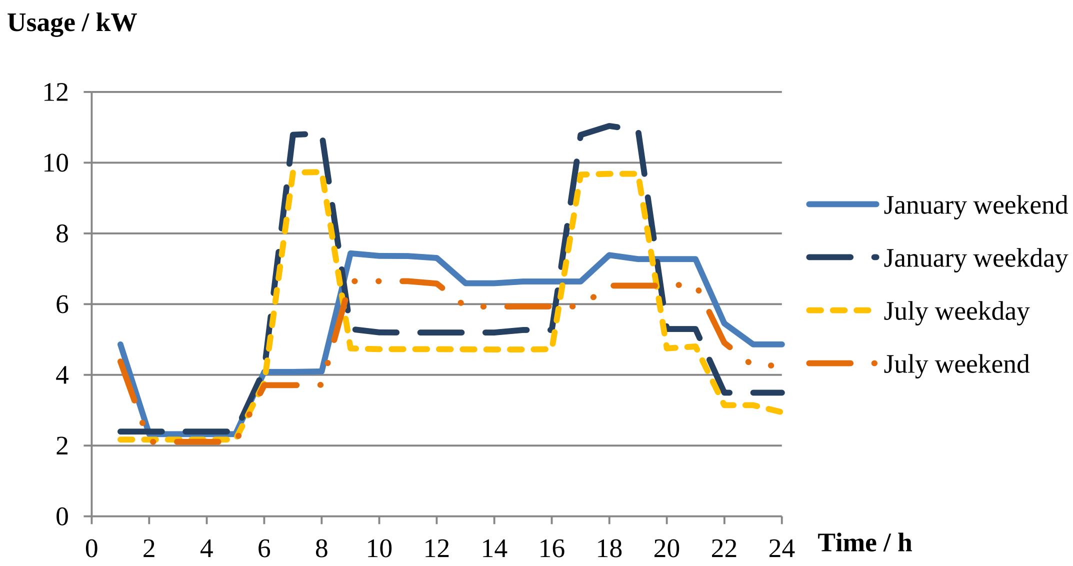

Figure 3.6: Harlyckegatan 7 estimated hourly electricity usage.

After the current case was estimated, the case for the BEN requirement in regards to the energy which can be produced by means of PVs was calculated and future case according to the renovation plan of Helsingborgshem was applied, see Table 3.4. Helsingborgshems's plan is to replace the exhaust ventilation system, install heat exchangers and air heat source heat pumps. The investigation of how heat pumps and heat exchangers can affect the electricity usage was conducted (Brown, Burke-Scoll, & Stebnicki, 2011). Two cases were considered: a +30% increase of the existing electricity usage in case if only the heat exchanger will be added and +50% to the existing electricity usage in case the air source heat pump will be installed as well. This increase occurs due to the installation of the heat exchanger and additional air source heat pumps in the buildings which will increase the overall electricity usage of the buildings. The estimated current and future usages can be seen in the Table 3.5. In case of Tyringegatan 292 only the roof of the building was planned to be renovated therefore the current energy use will match with the future energy use in the upcoming years of renovation.

Table 3.5: Current and future electricity usage for the considered buildings.

	Edwin Berlings gata 2	**Harlyckegatan 7**	**Tyringegatan 292**
Current energy use / (kWh, year)	17 790	45 807	28 642
Energy use according to BEN requirements / (kWh, year)	14 900	36 725	19 114
Estimated future energy use 1 / (kWh, year)	19 398	48 742	-
Estimated future energy use 2 / (kWh, year)	22 382	55 087	-

3.7.3 PV system sizing

Three buildings with the best average irradiation and a high potential of receiving a permission from the building permit department from the municipality were considered for the PV implementation. Three different systems were designed for each case - the whole roof coverage, the annual electricity usage coverage and system with 10% overproduction, see Table 3.6. The objective of Helsingborgshem was to use the PV system in order to cover electricity usages which the company pays for. This electricity use includes elevators, general lighting, common laundry room, basement lighting and facilities, exterior lighting, ventilation fans and elevator rooms. The reason behind designing three types of the systems was to see the possibility of the battery storage implementation in case of the overproduction and compare the results with battery to the results without. The case with 10% overproduction was suggested by Helsingborgshem. A LCC analysis was calculated for each system and the best case was found. To get the most realistic result, the company Kraftpojkarna, whom are a seller of PVs, which Helsingborgshem worked with before, was contacted. Four different PV panels were suggested and considered for each case. In total, 24 cases for each building were implemented and the best case according to the LCC, LCA and architectural integration was found, see Figure 3.7.

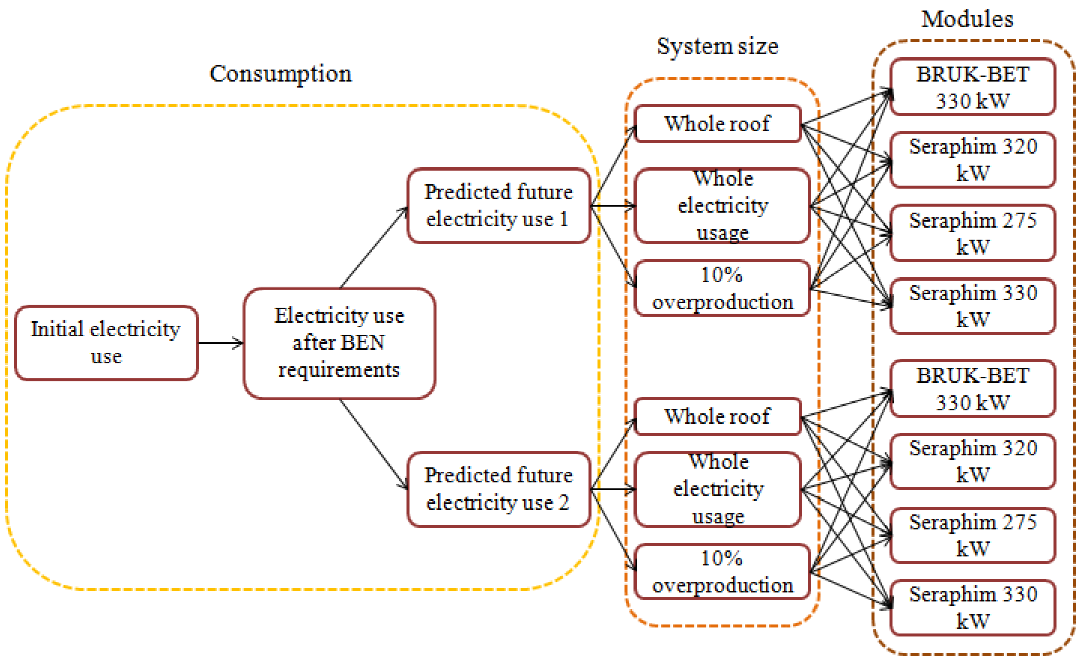

Figure 3.7: The PV system design process.

Table 3.6: Array size for selected buildings.

Selected buildings	**Case 1 – Future usage**		**Case 2 – Future usage**		**Case 3 – Future usage**	
	1	2	1	2	1	2
Tyringegatan 292	17.8 kWp		14.5 kWp			
Edwin Berlings gata 2	33.7 kWp	33.7 kWp	19.8 kWp	22.5 kWp	8.5 kWp	13 kWp
Harlyckegatan 7	56 kWp	56 kWp	49 kWp	55 kWp	20 kWp	23 kWp

For the case of Tyringegatan 292, only two cases were considered due to the limited amount of space on the roof. Detailed photovoltaic analysis in System Advice Model (SAM) was used during calculations (NREL, 2010).

3.7.4 Selected companies and modules

Due to the fact that the idea of this thesis was to compare different solutions from different countries, preferably from different continents, several suppliers were contacted. Two manufacturers from China and Poland were considered accordingly - Seraphim and Bruk-Bet Solar. All the proposed panels can be seen in the Table 3.7.

Table 3.7: The investigated PV modules.

Country	Poland	China	China	China
Manufacturer	BRUK-BET Solar	Seraphim	Seraphim	Seraphim
Module type	Monocrystalline (black module)	Monocrystalline	Mono (black module)	Polycrystalline
Efficiency / %	16.97	16.9	17.01	16.49
Max. Power / Wp	330	275	330	320
Voltage at Max. Power / V	36.7	31.1	37.3	37
Current at Max. Power / A	9	8.85	8.85	8.65
Open circuit voltage / V	44.2	38.7	46.1	45.5
Short circuit current / A	9.6	9.12	9.14	8.96
Size / mm · mm	1960 · 992	1640 · 992	1956 · 992	1956 · 992

A power optimizer is embedded by the manufacturer to each model, which is a DC/AC converter replacing a traditional solar junction box. It increases the electricity output by tracking the maximum power point.

3.7.5 System losses

The system losses applied during simulations can be seen in the Table 3.8.

Table 3.8: System losses used during the study.

Irradiance losses	DC losses						AC losses and others	
Soiling loss / %	Modules mismatch/ %	Diodes and connections/%	DC wiring/ %	Tracking error/%	Name-plate/%	DC power optimizer loss/%	AC wiring/ %	Age /%
5	0	0.5	2	0	0	1	1	0.8

3.8 LCC

In this chapter the life cycle cost analysis is presented including the method used, initial costs, the investigation about current and future cash glow variables (interest rates, price growth rates) and sensitivity analysis.

The Net Present Value (NPV) which is also known as discounted cash flow method was used during calculations to provide the possibility for Helsingborgshem to see which of the proposed solutions was financially the most feasible. The net present value approach is considered to be the most accurate valuation approach for making the decision whether to invest in the project or not. This method allows comparing alternative solutions and revealing the most profitable ones and this was another reason of why it was used during calculations as several proposals of PV renovation were considered. The formula of the geometric gradient series was used during calculations due to the fact that payments are distributed uniformly but differs by the constant value (See formula 1)

$$P = A_1 * \left(\frac{1-(1+g)^N*(1+i)^{-N}}{i-g}\right) \quad (1)$$

Where A_1 - payment at the year 1 (in this thesis year 1 is equal to year 2020), g - price growth rate, i - interest rate, N - number of periods.

The time frame for the analysis of 25 years was considered due to the warranty period of PV panels. The life expectancy of inverters was assumed to be 15 years. The process of the LCC analysis can be seen in the Figure 3.8. The analysis was performed starting with the year 2020 due to the fact that the building renovation will not start earlier. It should be noted that the price of the roofing material is not included in this study due to the fact that the building is going to be renovated.

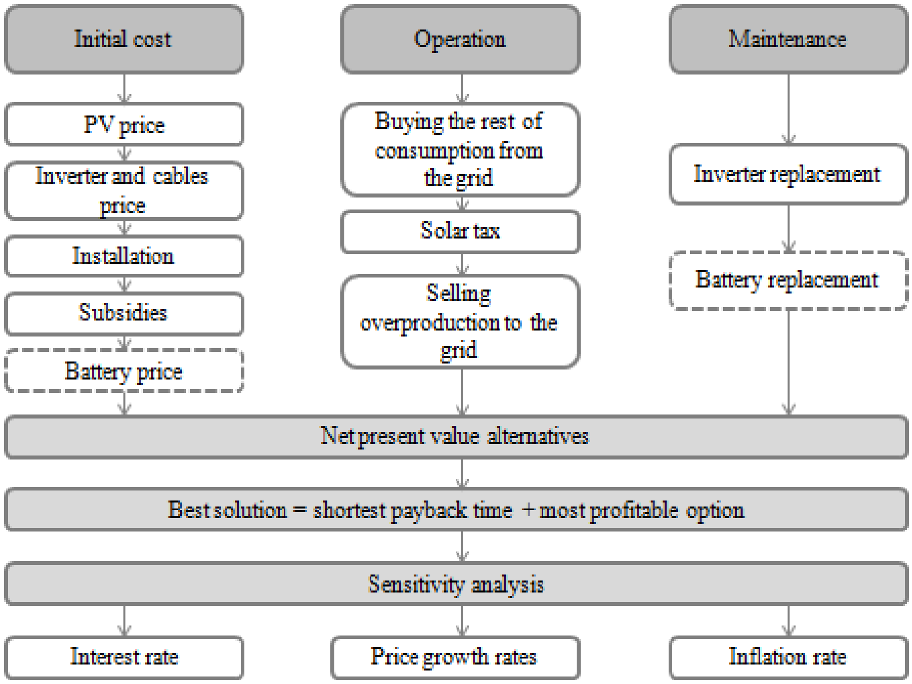

Figure 3.8: The LCC analysis process.

3.8.1 Initial cost

The initial cost considered in the LCC includes the price of PV panels, inverters, power optimizers, installation and lifting costs. The prices can be seen in the Tables 3.9 – 3.11.

Table 3.9: The PV prices.

Company	BRUK-BET 330 kW	Seraphim 320 kW	Seraphim 330 kW	Seraphim 275 kW
Price/SEK	1 995	1 440	1 786	1 487

The prices for the inverters were estimated from the price from Kraftpojkarna, see Table 3.10.

Table 3.10: The prices for inverters.

Company	SolarEdge	SolarEdge
Capacity/kW	25	17
Price/SEK	16 987	12 593

Table 3.11: The installation prices.

Montage cost/(SEK/hour)	Electrician cost/ (SEK/hour)
450	500

Lifting the panels to the roof was estimated to be 15 000 SEK.

3.8.2 Governmental subsidy

In Sweden anyone can apply for a subsidy from the government for their complete solar system installation. The government in Sweden has announced that annually, 50 million Swedish Crowns will go into the funding of solar systems (2017-2019). In Helsingborg, it is the county government of Skåne region, called Länsstyrelsen Skåne, which provides grants to the applications. The subsidy for companies, including government owned ones, is 30 % of the total cost, containing installation costs. The upper limit of the subsidy is 1.2 million Swedish Crowns and also there is a maximum limit of 37 000 SEK excl. VAT per kW_p. The subsidy can only contain one system per building or one system per property if the system in built on the ground. The support cannot be combined with any other subsidy (Länsstyrelssen Skåne, 2017). For a company the application should be made to the county government before the project has started.

3.8.3 Electricity price

The price of electricity that Helsingborgshem purchases fluctuates and consists of the following: Electricity cost, contract deal, electricity certificate fee, additional fee for hydropower electricity, energy tax, VAT 25 %. The energy tax in the southern part of Sweden changed on the 1 of January 2017 to 0.295 SEK/kWh (Skatteverket, 2016). Throughout the years, the trend shows that this tax on consumed electricity will increase further. Therefore, there is probability that the electricity price is going to be higher in the future and was therefore set to 0.34 SEK/kWh. Cost of electricity for the building can be seen in the Table 3.12.

Table 3.12: The prices for electricity.

Tyringegatan 292 / (SEK/kWh)	Edwin Berlings gata 2 / (SEK/kWh)	Harlyckegatan 7 / (SEK/kWh)
0.9438	0.9061	0.9109

The price of the electricity is different from building to building due to the different contract deal made with Öresundskraft, which is the electricity company owning the grid in the Helsingborg region.

3.8.4 Solar tax

The solar tax will be reduced on the 1 of June 2017 from 0.292 SEK/kWh to 0.005 SEK/kWh if the smaller producing facilities together reach 255 kW of peak power. Therefore, the value of 0.005 SEK/kWh was chosen since Helsinborgshems peak power is already at 235 kW in 2017.

3.8.5 Overproduction and storage

During PV system design, the overproduction of electricity was calculated and the option of selling back to the grid was considered. The value generated by selling electricity back to Öresundskraft is 0.4 SEK/kWh.

The possibility of the battery installation was considered for the best case of one of the buildings after the LCC analysis. The Tesla power wall was selected due to the relatively low price on the market and the reliability of the company. Price for one battery including installation cost and VAT is 75 500 SEK (Tesla, 2017).

3.8.6 Inflation rate

According to the Swedish national bank (Riksbanken), the current inflation rate in Sweden was 1.3 %, in March 2017. The fluctuation of the interest rates from 1988 to 2017 can be seen in the Figure 3.9. Based on this, the inflation rate during calculations is considered to be 1.5%.

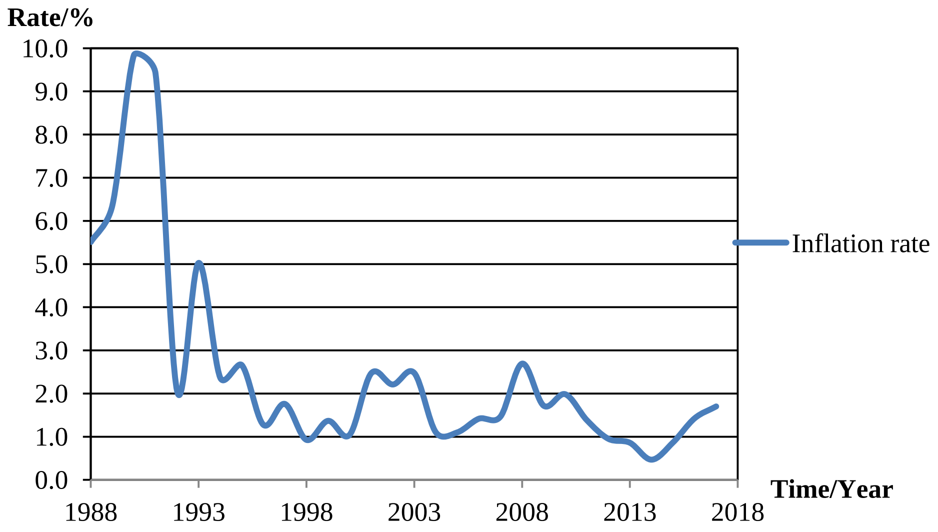

Figure 3.9: Inflation rate fluctuation in Sweden (Statistiska centralbyran, 2017).

The current interest rate in Sweden is considered to be -0.5% (Trading economics, 2017). The Trading economics forecast based on the analysts' expectations and autoregressive integrated moving average model is considered to be -0.5%. During the analysis, nominal interest rate i_n was used and calculated as $i_n = i_r + k = -0.5\% + 1.5\% = 1\%$.

3.8.7 Price growth rate of electricity

Wholesale electricity price in Sweden went down by 65% from 2010 to 2015 (Hirth, 2016). The reason for that could be a decrease in the energy demand, increased electricity supply from renewables, declined prices for fossil fuels and GHG emissions (Hirth, 2016). The value of -0.5% was considered for the study.

3.8.8 Price growth rate of PV panels

The continuous expansion of the PV market has caused that the price rate of change for monocrystalline and polycrystalline photovoltaics has been negative for the past 3 years. The statistics for Chinese market have been taken from PVxchange and can be seen in the Figure 3.10 (Pvxchange, 2017).

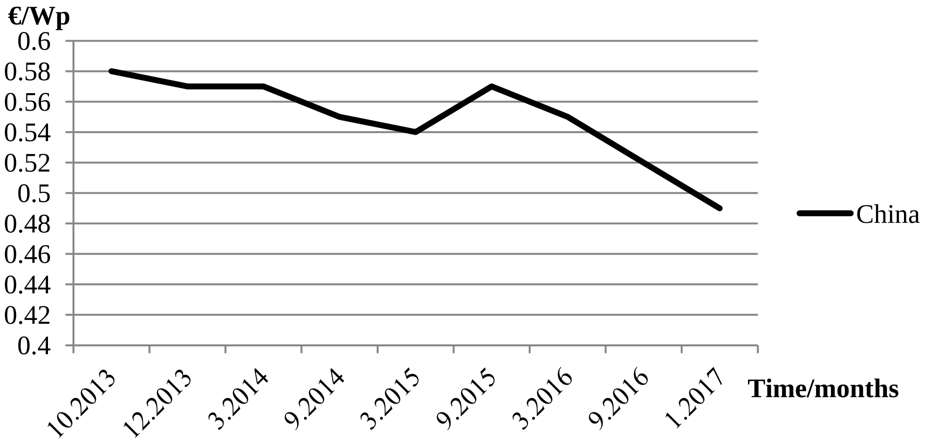

Figure 3.10: The price growth rate of PVs in China.

According to the Figure 3.10, the predicted future price growth rate for China is -2%. The price growth rate for inverters is considered to be the same as PV.

Due to the planned expansion of the PV market in Poland and due to the EU regulations of using 15% of the energy from renewable sources, considered in this thesis, PV price growth rate for Poland was set as -1% (eur-lex, 2009).

3.8.9 Sensitivity analysis

A sensitivity analysis is a technique used to test different values of certain variables to see how sensitive the calculations results are to the assumptions (Park, 2013). A sensitivity analysis is sometimes called a "what if analysis" and it shows what happens to the NPV in case the variable changes. In this thesis, variables such as price growth rates and interest rate were considered to be fluctuating and are included in the sensitivity analysis. The values are based on the analysts' expectations and can be seen in the Table 3.13.

Table 3.13: The sensitivity analysis of the variables.

Cash flow variables	Low (%)	Most likely (%)	High (%)
Interest rate	-1	-0.5	0.5
Inflation rate	0.5	1.5	2.5
Price growth rate (electricity)	-2	-0.5	2
Price growth rate (PV panels) China	-3	-2	0
Price growth rate (PV panels) Poland	-2	-1	0.5

3.8.10 Degradation period

Over the period of the life span, PV module performance decreases each year. According to the study conducted by National Renewable Energy Laboratory (NREL), the median degradation rate for Si-based PV panels is 0.5% (Jordan & Kurtz, 2012). The analysis of the proposed PV modules' description showed that degradation rate for the panels is 0.8% per year.

3.9 Integration of Photovoltaics

In regards to the integration of PVs, the visualizations were made to provide a better understanding on the way the investigated panels look on the roofs of the buildings. Several cases were selected in order to see the difference between different panels. The best option from the LCC analysis point of view was selected and the best option from the integration point of view was chosen and the results were analyzed.

3.10 Life Cycle Assessment of transportation of Photovoltaics

Life Cycle Assessments is a method used to determine how big the environmental impact is for a product or a service (Aymard, 2016). It usually considers the whole life cycle, a so called "Cradle-to-Grave", but it can also be applied to parts of the life cycle. This thesis covers the transportation impacts from the producer to the end customer, in this case being Helsingborg. The two producing companies that were considered were: Bruk-Bet Solar (Poland) and Seraphim (China). The transportation method and estimated distance from the two companies to Helsingborg can be seen in Figure 3.11.

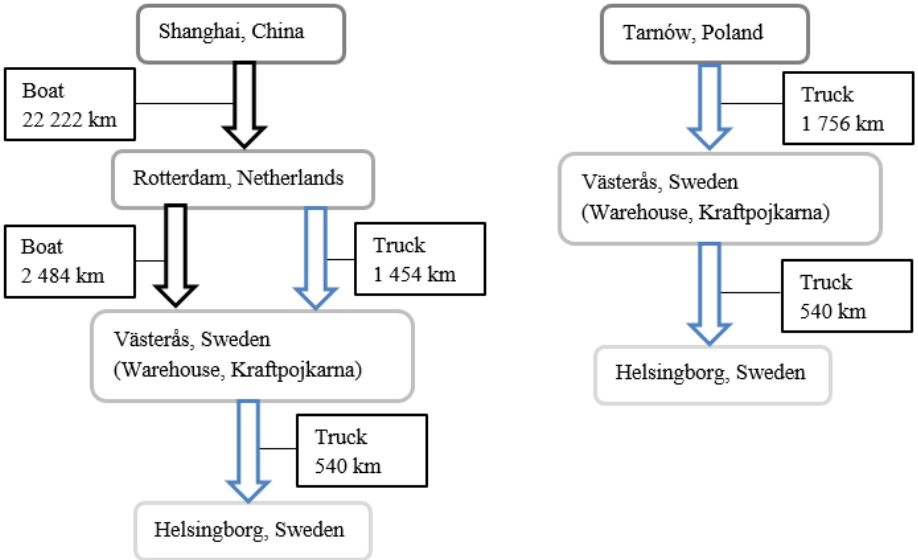

Figure 3.11: The scheme of transportation routes and distances from the production to the customer.

There are two different routes the panels from China can take to the warehouse of Kraftpojkarna in Västerås. Therefore, it was divided into two cases. First, for both cases, the panels are transported with a container ship with a total estimated capacity of 27 500 tons from Shanghai to Rotterdam. Thereafter, they can either go with a smaller cargo boat with the capacity of approximately 1 200 tons to Västerås or by a truck. Case 1 is with the boat and Case 2 with the truck. From Västerås to Helsingborg, the goods are transported with a truck.

By using the software OpenLCA edition 1.6.2, a LCA from Gate-to-Gate was assessed. In total three different weights were considered whereof from China they were 24 kg, 19 kg and the 21.5 kg panel from Poland, see Table 3.14.

Table 3.14: The weights of the panels considered in the study.

	Seraphim 320 & 330 poly	Seraphim 275 mono	BRUK-BET Solar 330 mono
Weight / kg	24	19	21.5

3.10.1 Impact categories and normalization

The impact categories that were chosen to be addressed in this thesis were: Climate change, Acidification, Photochemical ozone formation and Particulate matter/Respiratory Inorganics. The impact categories were chosen by partially having a high to medium overall robustness and partially since the outcome of the transportation emissions affected these impact categories the most, see Table 3.15.

In order to bring every impact to the same scale, a normalization was conducted (Aymard, 2016). An equation was used where the result of each impact were divided with the selected reference value, see Equation 1 and Table 3.15 for the used normalization factors.

$$N_i = \frac{S_i}{R_i} \quad (1)$$

Where, *i* is the selected impact category and N_i is the normalized outcome. S_i stands for the characterized impact under study and R_i for the characterized impact of the reference system.

The normalization factor used for these impacts were taken from EU-27 related domestic inventory in 2010, when there were 499 million inhabitants in Europe (Benini, et al., 2014).

Table 3.15: Normalization factors for EU-27 used in this study (Benini L. M., 2014).

Impact category	**Unit**	**Domestic**	**Normalization Factor per Person (domestic)**	**Overall Robustness**
Climate change	kg CO_2 eq.	4.60E+12	9.22E+03	Very High
Acidification	Mol H^+ eq.	2.36E+10	4.73E+01	High
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	3.17E+01	Medium
Particulate matter/Respiratory Inorganics	kg $PM_{2.5}$ eq.	1.90E+09	3.80E+00	Very High

4 Result

This chapter represents the results from the analysis which was performed during this master thesis. First, the results from the irradiation analysis are shown together with the best possibility of implementing solar panels, the whole combined list can be seen in Appendix A. Thereafter, the results from the system design of PVs are shown with the implementation of different panels. Furthermore, the results from LCC analysis are presented and the sensitivity analysis for the best cases is shown. After that, the visualizations of the buildings with two of the investigated panels and lastly the LCA analysis results are summarized.

4.1 Solar irradiation

The results from the solar irradiation analysis are combined with the municipality's list of buildings which are likely to get the permission from the building department, see Table 4.1 for the final list of the average radiation of the whole roof which was studied.

Table 4.1: The very good irradiation and likely possibility list.

Type of renovation	**Name of the area**	**Address**	**Average Solar irradiation on the roof / (kWh/m² and year)**	**Roof area / m²**
Full renovation	Isbanan 1	Harlyckegatan 7	1 037	440
	Tapiren 1	Jönköpingsgatan 37	1 077	270
	Tapiren 1	Jönköpingsgatan 39	1 075	270
	Tapiren 1	Jönköpingsgatan 41	1 072	273
	Tapiren 1	Edwin Berlings gata 2	1 082	270
	Tapiren 1	Edwin Berlings gata 8	1 077	270
Roof renovation	Ella 1	Tyringegatan 2	1 107	102
	Ella 1	Tyringegatan 4	1 096	102
	Ella 1	Tyringegatan 6	1 079	104
	Ella 4	Tyringegatan 70	1 113	105
	Ella 4	Tyringegatan 72	1 114	101
	Ella 4	Tyringegatan 74	1 112	102
	Rosa 2	Tyringegatan 292	1 114	102
	Rosa 3	Tyringegatan 294	1 112	102
	Rosa 3	Tyringegatan 296	1 114	102
	Rosa 3	Tyringegatan 298	1 114	102
	Tyskland 26	Nedre Holländaregatan 24	1 028	98
	Tyskland 26	Gustav Adolfs Gata 12	1 047	96
	Belgien S10	Gasverksgatan 28B	1 053	97

In Figure 4.1 the numbers that are marked with red are on the resulting list in Table 4.1 by having an average solar radiation level over 1020 kWh/m² and year. The radiation result of the neighboring roofs showed a lower average value because of shading rather than orientation and did therefor not make the final list. The irradiation map can be seen in the Appendix A.

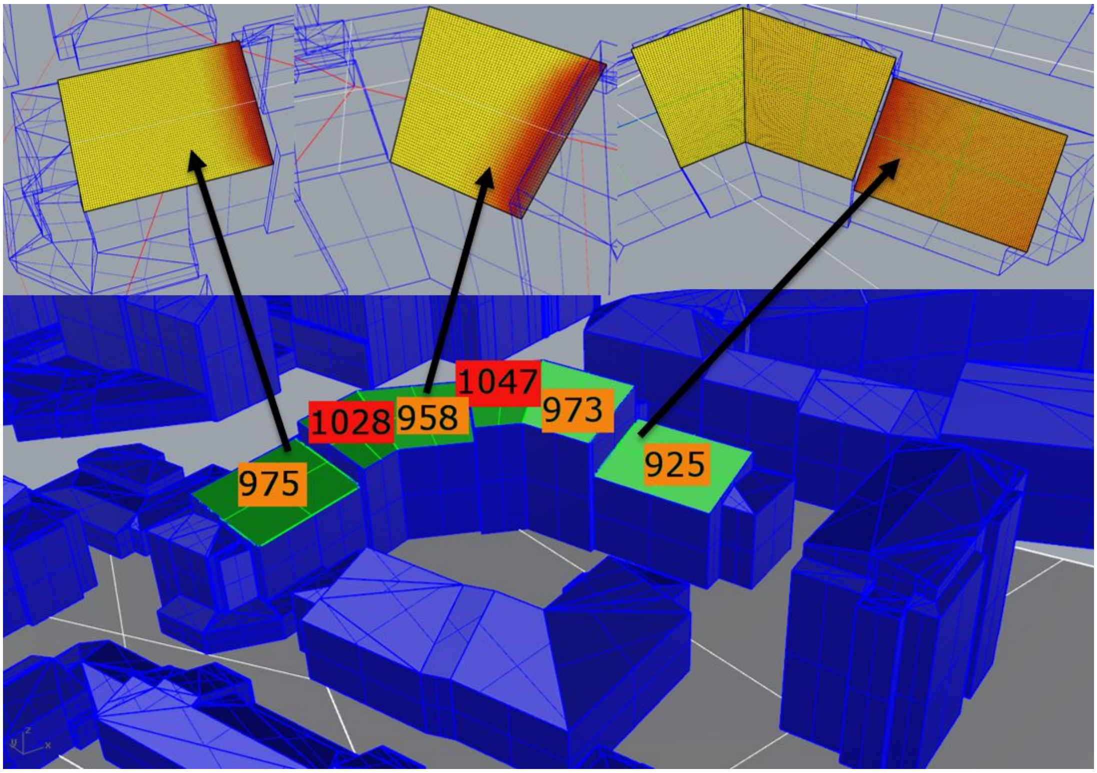

Figure 4.1: The resulting number of the average solar radiation in kWh/m² and year of the area Tyskland 26.

4.2 PV system design

In this chapter the results of the PV system sizing for three buildings can be seen.

4.2.1 Tyringegatan 292

The results for the case of Tyringegatan 292 can be seen in the Table 4.2.

Table 4.2: The results of the system design of the future case 1, Tyringegatan 292.

System size/kWp	Panel	System energy (AC) annually/kWh	Overproduction/kWh	Annual electricity use coverage/%	Amount of panels
14.5	Srp 320	13 980	8 536	28	44
	Srp 275	14 313	8 855	28	55
	Srp 330	13 071	7 752	28	44
	BEM 330	13 294	7 991	28	44
17.8	Srp 320	16 544	10 811	30	54
	Srp 275	16 739	10 982	30	63
	Srp 330	16 697	10 995	30	54
	BEM 330	16 516	10 857	29	54

4.2.2 Edwin Berlings gata 2

The results from PV system sizing for Edwin Berlings gata 2, future case 1, can be seen in the Table 4.3.

Table 4.3: The results of the system design of the future case 1, Edwin Berlings gata 2.

System size/kWp	Panel	System energy (AC) annually/kWh	Overproduction/kWh	Annual electricity use coverage/%	Amount of panels
33.7	Srp 320	30 834	23 471	38	102
	Srp 275	35 191	27 377	40	136
	Srp 330	31 026	23 437	39	102
	BEM 330	31 556	23 823	40	102
19.8	Srp 320	18 445	11 678	35	60
	Srp 275	18 846	12 005	35	72
	Srp 330	18 259	11 537	34	60
	BEM 330	18 529	11 741	35	60
8.5	Srp 320	7 687	2 676	26	24
	Srp 275	7 169	2 262	25	28
	Srp 330	7 785	2 728	26	26
	BEM 330	7 896	2 788	26	26

As it can be seen from Table 4.2, the maximum annual electricity use that can be achieved with the PV system is 40%. Therefore the battery implementation was considered in the study and compared with the option to sell back to the electricity grid.

4.2.3 Harlyckegatan 7

The results for the case of Harlyckegatan 7 can be seen in the Table 4.4.

Table 4.4: The results of the system design of the future case 1, Harlyckegatan 7.

System size / kWp	Panel	System energy (AC) annually/kWh	Overproduction / kWh	Annual electricity use coverage / %	Amount of panels
56	Srp 320	51 389	34 483	35	170
	Srp 275	54 671	37 594	36	210
	Srp 330	51 474	34 858	35	170
	BEM 330	52 236	35 444	35	210
49	Srp 320	45 240	28 991	34	135
	Srp 275	42 424	26 227	33	162
	Srp 330	41 104	25 429	35	135
	BEM 330	41 711	25 867	33	162
20	Srp 320	17 324	5 658	24	56
	Srp 275	16 463	5 229	24	64
	Srp 330	16 998	5 630	24	56
	BEM 330	17 248	5 752	24	64

4.3 The LCC analysis

The results of the LCC analysis include the LCC calculations for the investigated buildings, battery implementation for one building and sensitivity analysis for the best cases. The vertical line in the following graphs shows the payback time for each case.

Due to the big load of data, only future case 1 for all the buildings is shown in the results, future case 2 can be seen in the Appendix C-D. For the case of Tyringegatan 292, all the cases are presented in this chapter.

4.3.1 Tyringegatan 292

The results from the LCC analysis for all the investigated cases for Tyringegatan 292 can be seen in the Figures 4.8 – 4.9 and Table 4.6. The base case in the figures is explained as the NPV with no PV installed and all other cases are the different PV modules which were explained earlier.

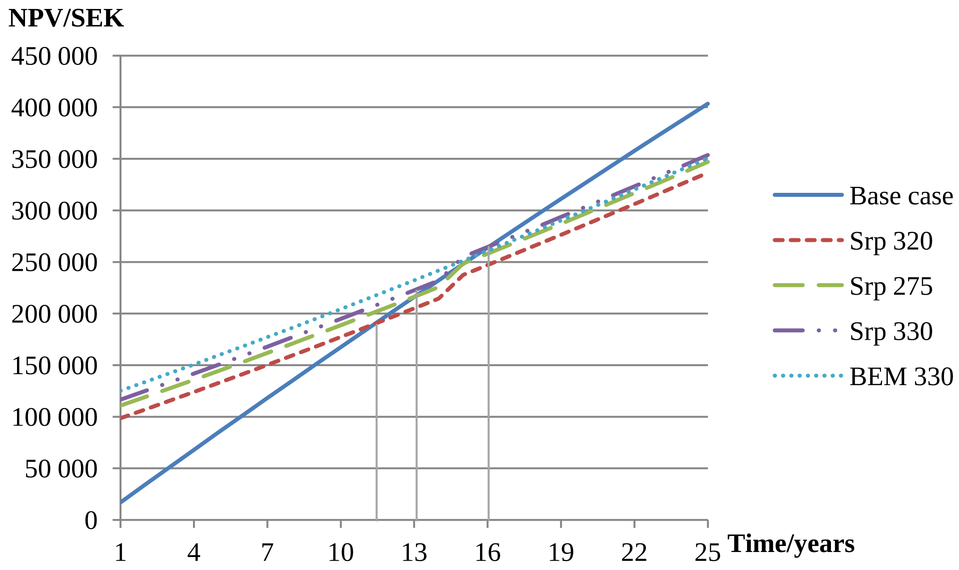

Figure 4.2: The LCC analysis for the horizontally placed panels (17.8 kWp).

The sudden increase in NPV on the Figures can be explained by the need of inverters replacement by the end of the year 15.

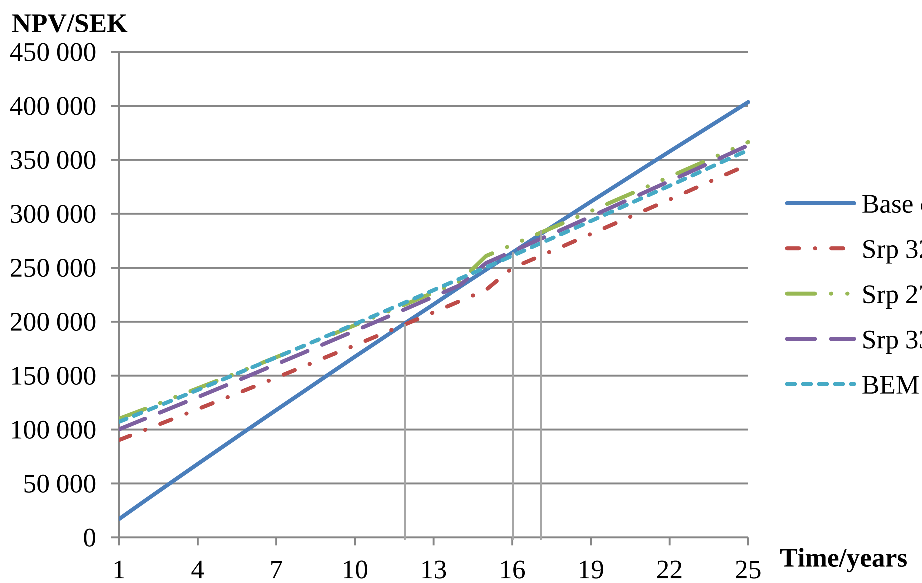

Figure 4.3: The LCC result for the vertically installed panels (14.5 kWp).

Table 4.5: Total amount of savings over the whole calculation period and payback time.

	Total savings/SEK				Payback time/years			
	Srp 320	Srp 275	Srp 330	BEM 330	Srp 320	Srp 275	Srp 330	BEM 330
Panels installed vertically	57 755	37 003	40 021	44 419	14	15	15	16
Panels installed horizontally	66 912	56 451	49 754	52 810	12	13	14	16

As it can be seen from the Table 4.5, the result shows that according to the LCC performance, a horizontally placed panels system with Chinese modules Seraphim 320 has biggest amount of savings of 66 912 SEK in 25 years and shortest payback time of 12 years.

Sensitivity analysis for the best LCC result can be seen in the Figures 4.4 - 4.5.

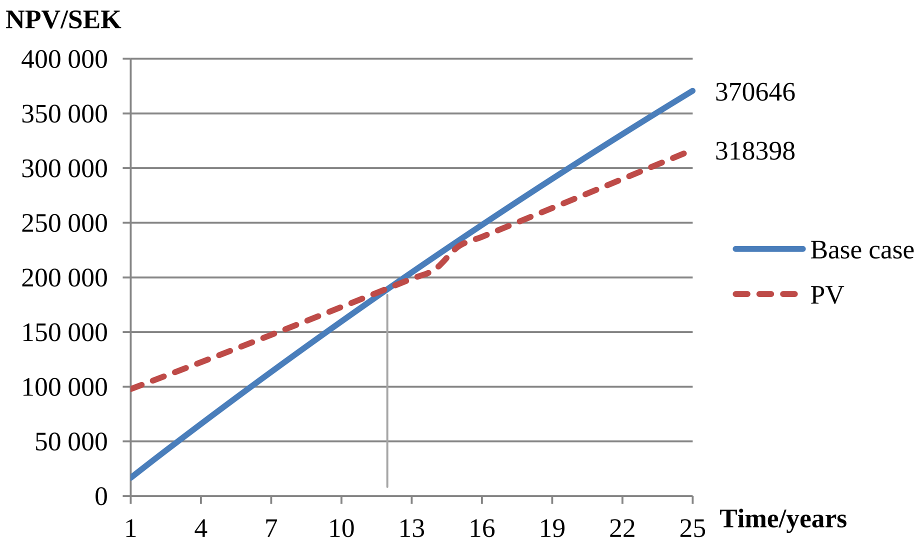

Figure 4.4: The sensitivity analysis for the lowered cash flow variables.

For lowered cash flow variables, the amount of savings over the calculated period is 52 248 SEK.

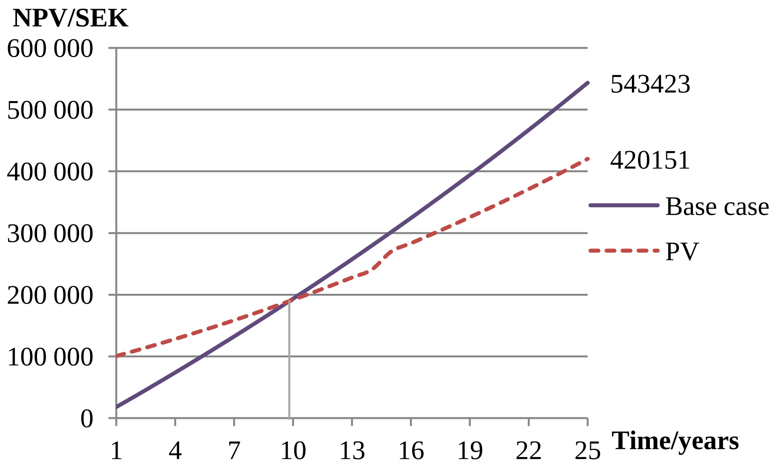

Figure 4.5: The sensitivity analysis for the overstated cash flow variables.

For overstated values in sensitivity analysis the result of total savings is 123 272 SEK.

4.3.2 Edwin Berlings gata 2

The LCC analysis for the future case 1 of Edwin Berlings gata 2 for all the explored modules can be seen in the Figures 4.6 – 4.9.

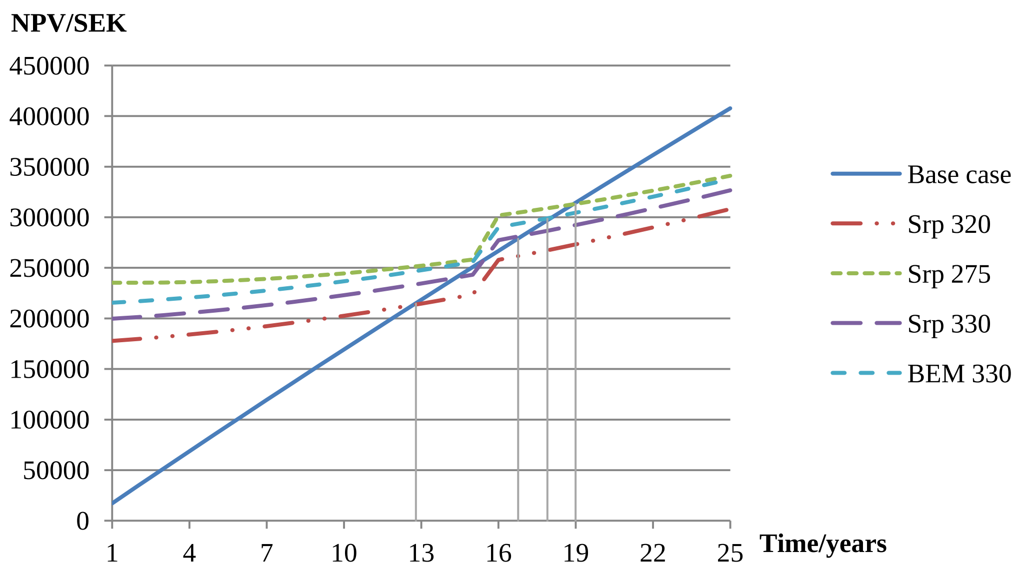

Figure 4.6: Resulting LCC analysis of Edwin Berlings gata 2, future case 1, whole roof coverage.

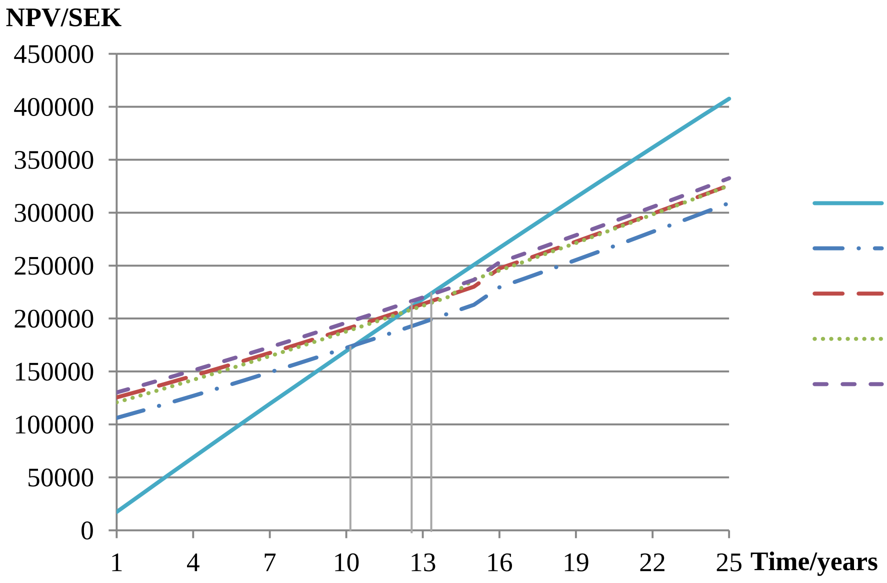

Figure 4.7: Resulting LCC of Edwin Berlings gata 2, future case 1, whole annual usage coverage.

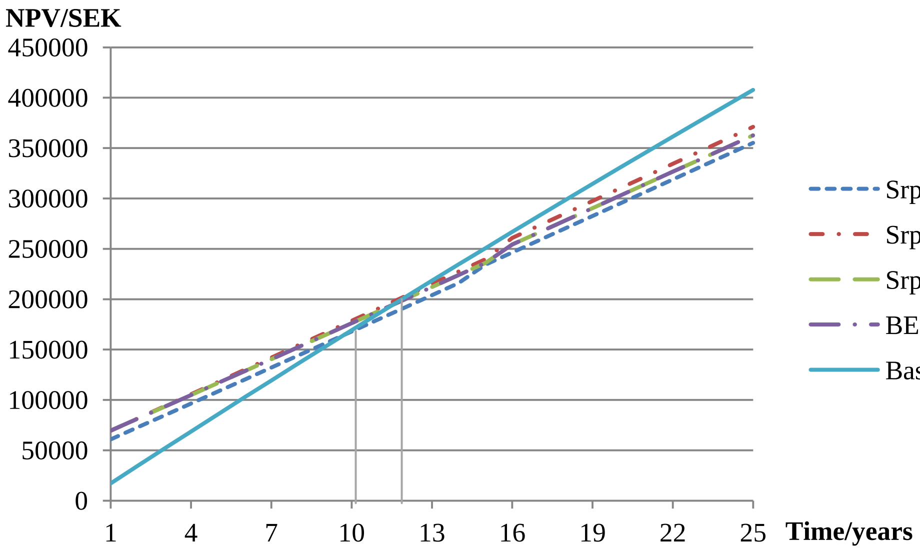

Figure 4.8: Resulting LCC analysis of Edwin Berlings gata 2, future case 1, 10% overproduction.

Amount of savings in each case can be seen in the Table 4.6.

Table 4.6: Resulting savings of Edwin Berlings gata 2, future case 1.

	Total savings/SEK				Payback time/years			
	Srp 320	Srp 275	Srp 330	BEM 330	Srp 320	Srp 275	Srp 330	BEM 330
33.7 kWp	105 440	78 102	90 317	77 671	13	18	17	18
19.7 kWp	102 254	86 221	86 255	78 650	11	13	12	13
8.5 kWp	54 418	39 074	47 170	44 284	10	12	12	12

As it can be seen from Figures 4.6-4.9 and Table 4.6, in case of the Future case 1, the shortest payback time as well as highest savings can be achieved with 19.7 kWp system and Srp 320 W panel. Battery storage for this case was considered and two batteries were selected. Results can be seen in Figure 4.9.

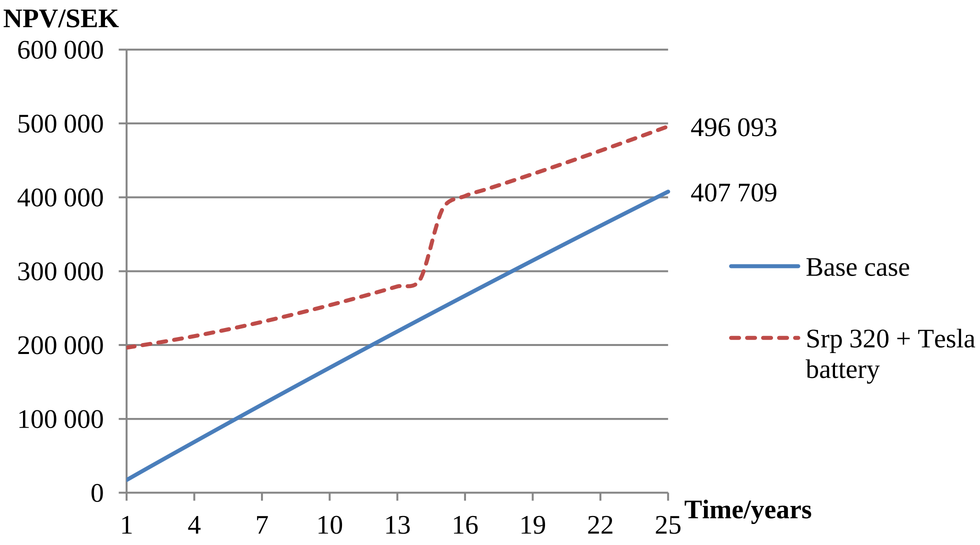

Figure 4.9: Resulting LCC for the possibility of using battery storage.

As it can be seen from the Figure 4.9, the battery implementation does not have a payback time in 25 years due to the battery replacement after 15 year and high price compared to the savings.

For the best case, a sensitivity analysis was performed and can be seen in the Figures 4.10 – 4.11.

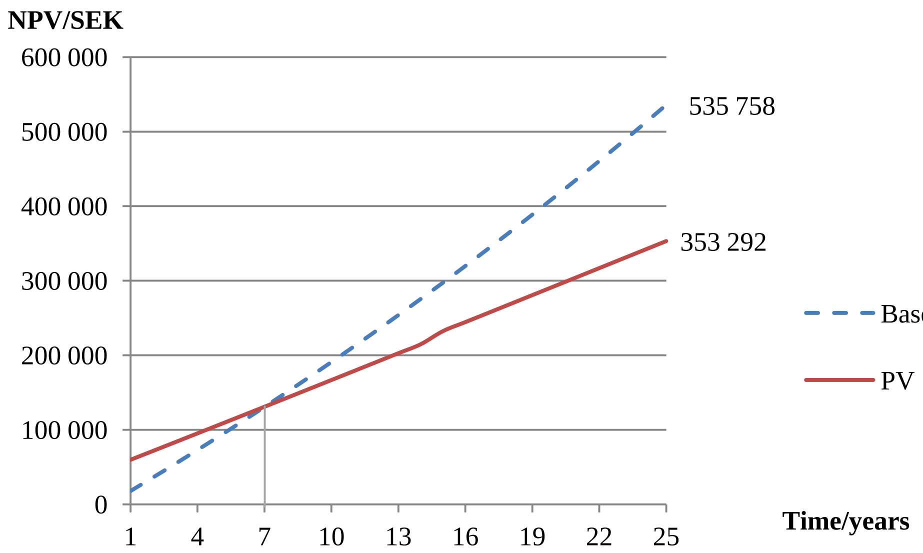

Figure 4.10: Sensitivity analysis for the overstated values.

For the sensitivity analysis of the overstated cash flow variables, the payback period is 7 years and final savings are approximately 182 500 SEK.

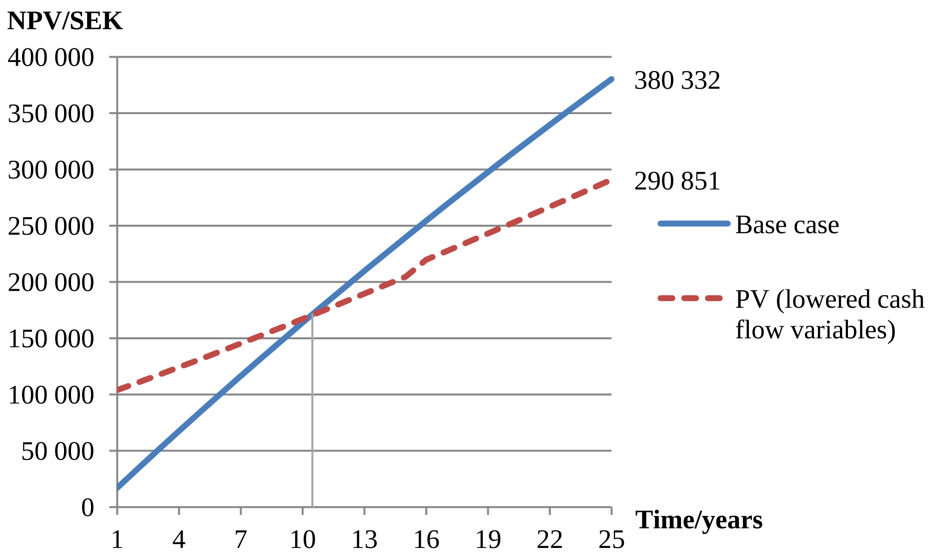

Figure 4.11: Sensitivity analysis for the lowered values.

For the results of the lowered values, payback time is 11 years and total amount of savings is 89 481 SEK.

4.3.3 Harlyckegatan 7

The LCC analysis for the future case 1 of Harlyckegatan 7 for all the explored modules can be seen in the Figures 4.12 - 4.14.

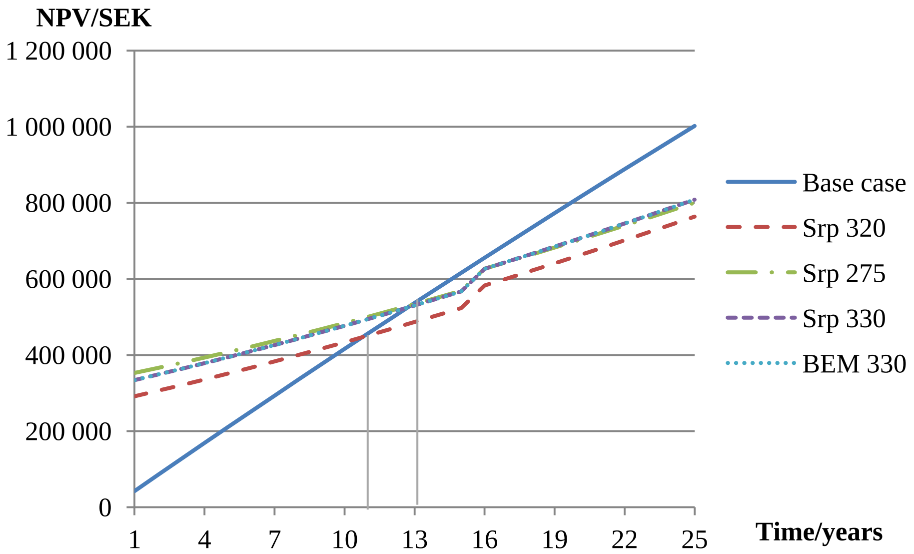

Figure 4.12: The LCC result for the 56 kWp system.

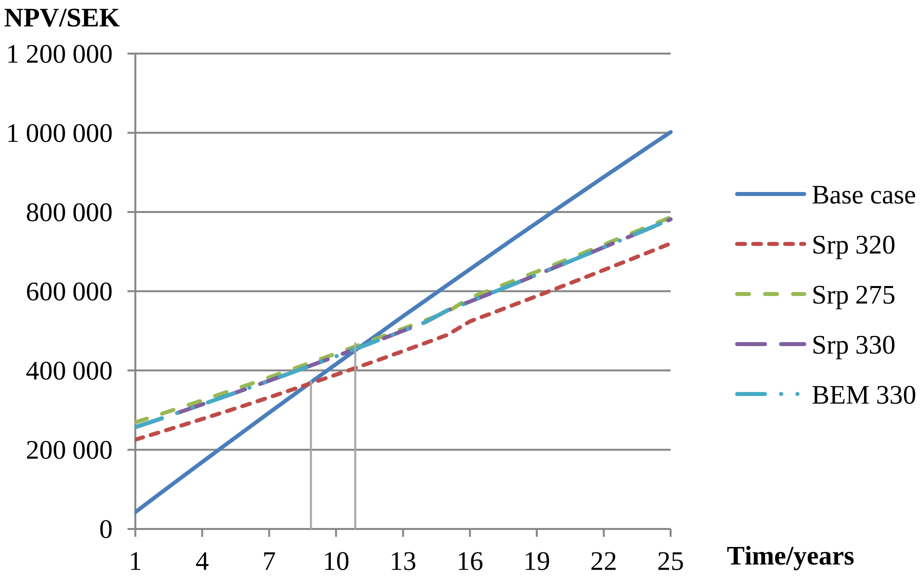

Figure 4.13: The LCC result for the 49 kWp system.

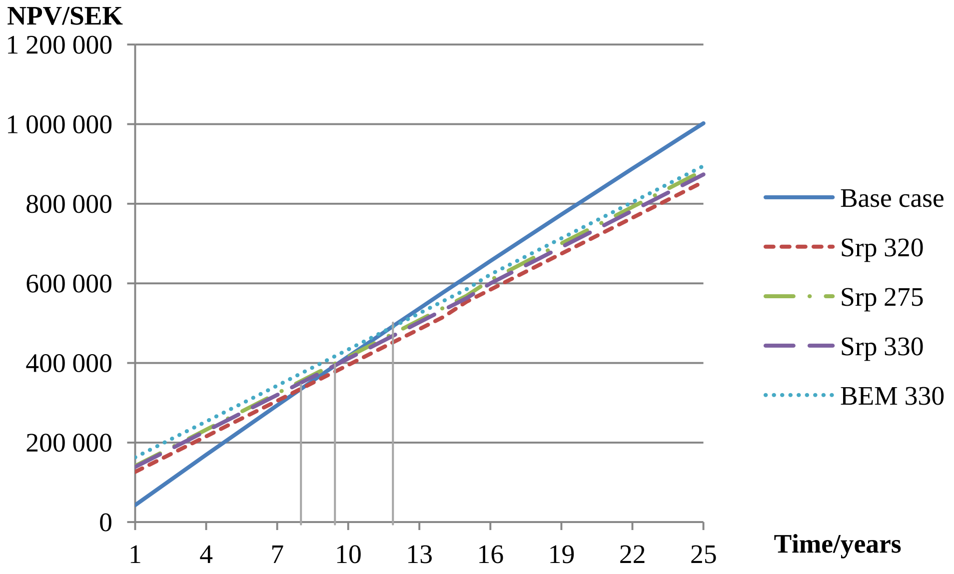

Figure 4.14: The LCC analysis for the 20 kWp system.

Table 4.7: The total savings and payback time.

	Total savings				Payback time			
	Srp 320	Srp 275	Srp 330	BEM 330	Srp 320	Srp 275	Srp 330	BEM 330
56 kWp	238 071	201 688	193 610	173 713	11	13	13	14
49 kWp	281 089	214 966	220 257	175 035	9	12	11	14
20 kWp	147 000	118 282	128 438	106 976	9	10	10	12

From Figures 4.12 – 4.14 and Table 4.7 it is seen that the Chinese panel Seraphim 320 has shortest payback period of 9 years and biggest total savings of 281 089 SEK for a system designed according to the annual usage.

The sensitivity analysis for the best LCC case was performed and is shown in the Figures 4.15 – 4.16.

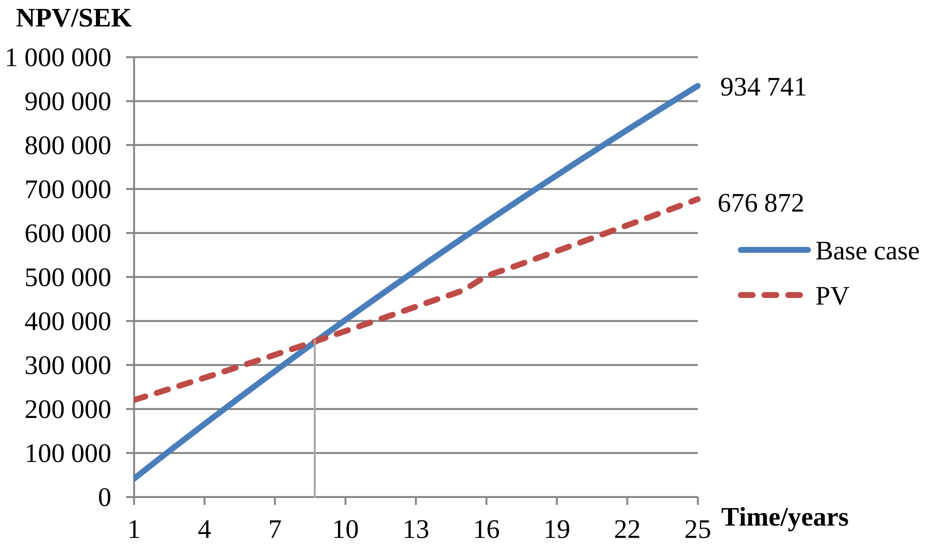

Figure 4.15: The sensitivity analysis for lowered values.

According to the sensitivity analysis performed for the low cash flow variables, the total amount of savings is 250 129 SEK.

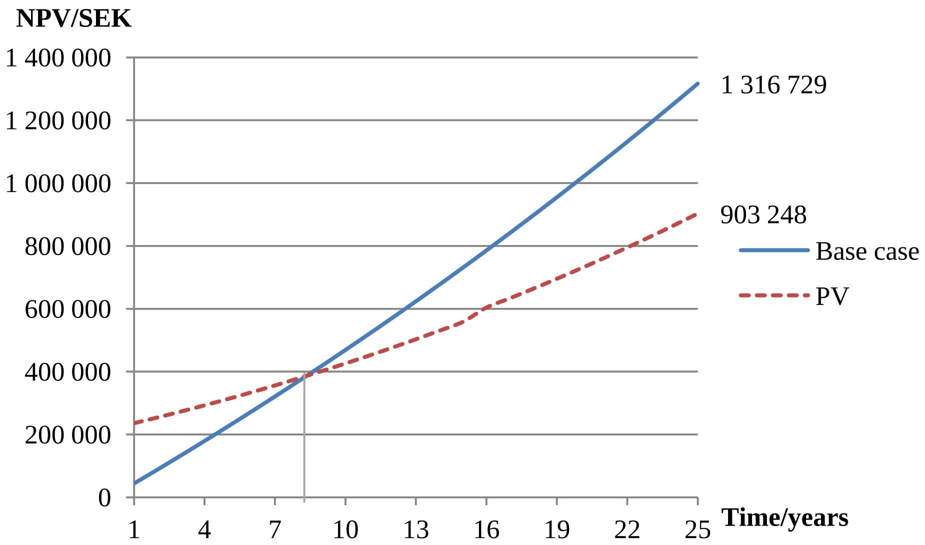

Figure 4.16: The sensitivity analysis for overstated cash flow variables.

For the overstated cash flow variables, the total amount of savings would be 413 481 SEK.

4.4 Visualizations of the three buildings

In this chapter the visualizations of the three buildings are presented, for the best LCC performance and also for the black Polish module for a better integration.

See Figure 4.17 for the visualizations of Tyringegatan 292.

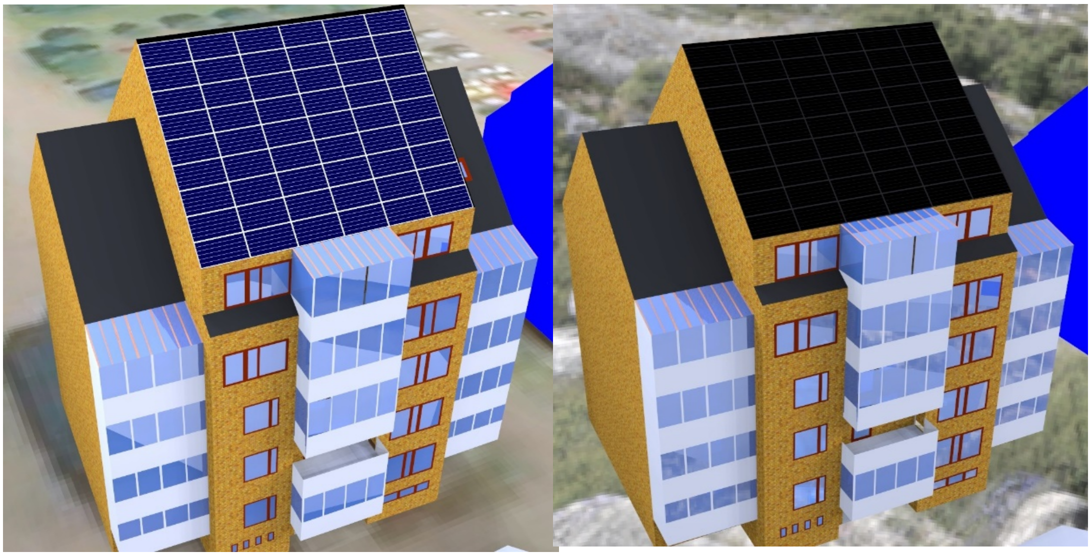

Figure 4.17: The best case of the LCC result visualization and to the right the BEM 330 panel, Tyringegatan 292.

The visualizations of Edwin Berlings gata 2 can be seen in the Figure 4.18 - 4.19.

Figure 4.18: Visualization of the best case system design in case of Edwin Berlings gata 2.

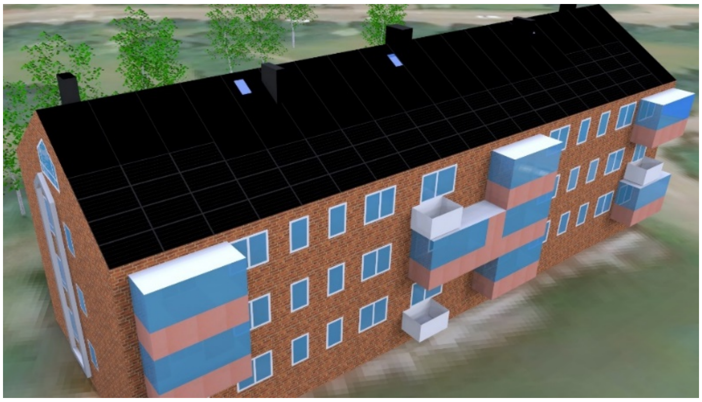

Figure 4.19: Visualization of the BEM 330 panel, Edwin Berlings gata 2.

Visualizations for Harlyckegatan 7 can be seen in the Figures 4.20-4.21.

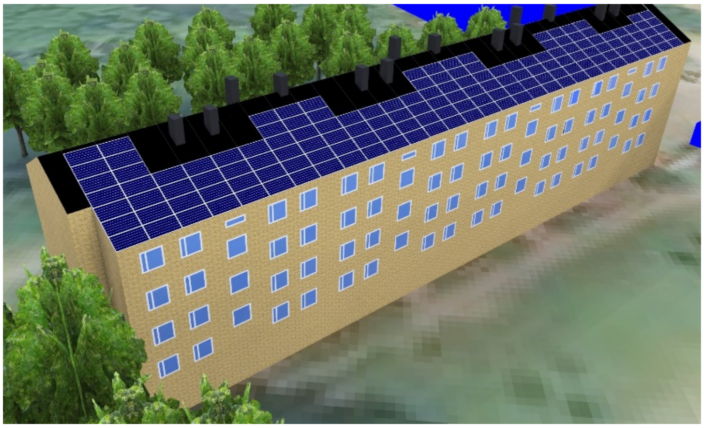

Figure 4.20: Visualization of the Srp 320 panel, Harlyckegatan 7.

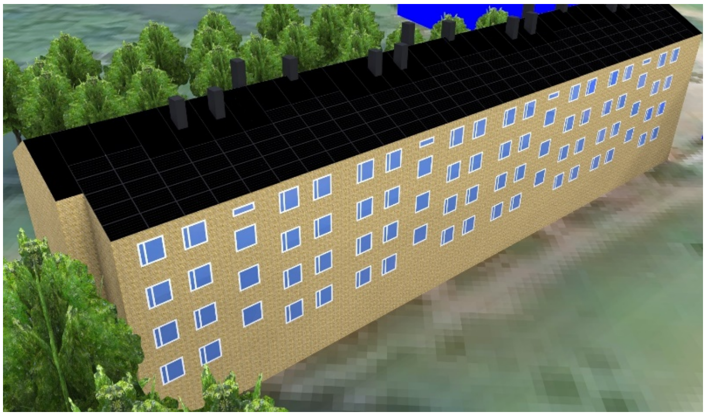

Figure 4.21: Visualization of the BEM 330 panel, Harlyckegatan 7.

4.5 Impact assessment of the transportation from factory to end customer

The two manufacture companies investigated in this thesis have their factories in Tarnów, Poland and Shanghai, China. The Figure 4.22 represents the result of the investigated impact categories for the different transportation cases. Case 1 represents the transportation route from Shanghai to Rotterdam by a container ship, then the cargo is transferred by a smaller boat to Västerås and thereafter by truck to Helsingborg. For Case 2 the difference is in the route from Rotterdam to Västerås the goods are transported by truck and then to Helsingborg the same way. Therefore, there is a difference in the impact category of Climate change, between the two.

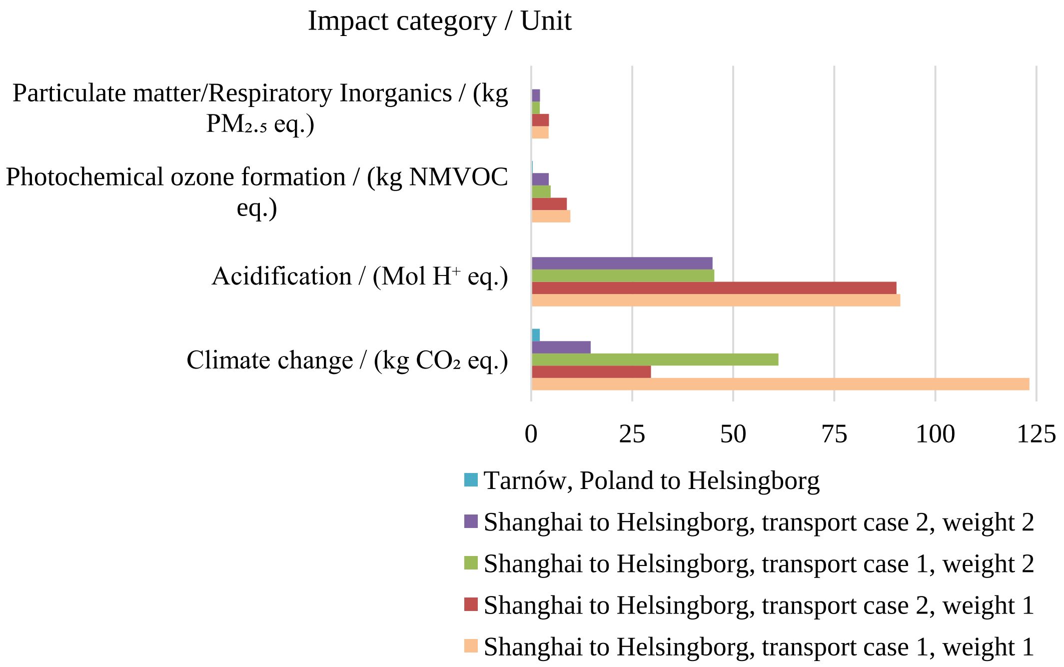

Figure 4.22: The total amount of impact between the different transportations cases, weight 1 being 24 kg and weight 2, 19 kg.

The result after the normalization using the normalization values from EU-27 is presented in Figure 4.23. There is a big difference in impacts between the panel weighting 24 and 19 kg from Shanghai to Helsingborg. This is due to the fact that the impact category of Acidification and Particulate matter/Respiratory Inorganics having a high or very high importance and therefore has a high normalization factor. The Climate change impact, thought being highly visible in the total impact category graph, is inexistent after the normalization. The difference between the highest normalized case and the lowest result, in the transportation emissions from producer to end customer, was 53 smaller measured per kg panel.

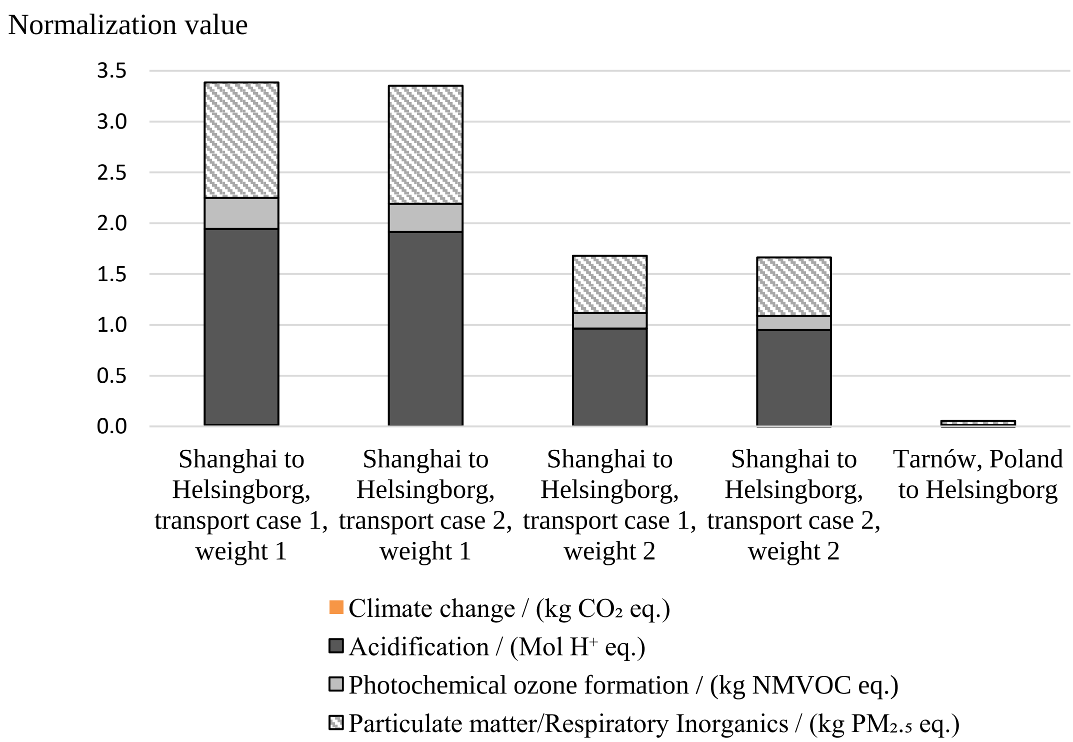

Figure 4.23: The summarized normalization value for the five transportation cases.

5 Discussion

The detailed analysis of the irradiation, with the applied building materials' reflections of the buildings' roofs, chimneys, neighbor buildings' windows and frames, did not affect the irradiation result of the roofs and was not considered during the analysis. The biggest difference in irradiation was the result of the vegetation and chimneys.

During this analysis it was clear that hourly electricity usage data is crucial while performing the PV implementation due to the fact that overproduction of the system depends on the solar irradiation which can change rapidly. By having only the monthly electricity use, it makes it impossible to see the actual overproduction and thus perform the LCC analysis.

The Swedish government supports the installation of PVs but the obstacles which the companies face while designing a system are still considerable and have to be taken into account. For example, the price for selling overproduced electricity to the grid is several times lower than the bought electricity which often makes company design a system according to lowering overproduction and thus lowering the system size. Helsingborgshem is discussing the possibility of sharing the electricity with their tenants and thus lowering the peaks which could decrease the price for electricity from Öresundskraft. This could open new possibilities for Helsingborgshem to install bigger systems. Due to still relatively high price of the battery on the market, energy savings from storing do not exceed the battery cost and thus not worth the investments. The investigation in regards to the future battery price showed the possibility of the future profitability.

Many PV panels are produced in China but it is important when buying PV panels to look at where and how it is produced. The PV panels produced in China consume significantly more primary energy in comparison to Europe producers. By choosing an alternative path for the transportation of PV panels, that is shorter from Shanghai to Rotterdam via the Northern Sea Route (NSR) instead of the Suez Canal, it can lead to lower emissions due to the shorter route. This means that the end result could imply that it is better from an environmental point of view to take the NSR, rather than the conventional Suez Canal Route. On the other hand, NSR is more expensive due to the cold weather and the need of the icebreaker.

Due to the fact that Chinese market is currently the biggest in regards to the PV production, they have the lowest price which European companies cannot compete with. Several studies were conducted about the several times higher environmental impacts coming from the embodied energy while producing PVs in China compared to European.

Currently, companies are faced with many decisions that have to be made in regards to the PV implementation. It is often hard to reach the most profitable system which is at the same time integrated and environmental friendly. At an early stage the purpose of the PVs has to be discussed and three possible options could be selected - the system with the shortest payback period and biggest total savings, the integrated system or the system with the lowest environmental impacts. While it is clear that the Chinese panels are worse in regards to the embodied energy and transportation to Europe, the price is still a decisive factor for many companies. This trend could be changed in the future by introducing the regulations about PV integration and more strict demands on environmental emissions of the product.

In the future when the PV prices are considerably lower, the PV system could be seen not just as an investment which is implemented on the roof but rather as a roofing material which would have a purpose of providing a shelter and also producing electricity. In this case the esthetics and integration of the PV roofing in the environment would have the same value as a profitability analysis.

6 Conclusion

The aim of this master thesis was to create a solar map for the buildings owned by Helsingborgshem with the selection of the most suitable buildings for PV implementation in regards to the solar radiation analysis and the building permit department possible clearance. Second objective was to make a study about the best modules from an integration, LCC and LCA point of view.

The findings taken from the irradiation analysis of the 89 buildings showed that most of the buildings have a pitched roof towards the South-West, South and South-East resulted in a very good irradiation according to the categorisation limits. Though, if the roof had an orientation towards the East or West, the results were merely reasonably good.

In regards to the building sensitivity list, the investigation showed that this could be an obstacle for Helsingborgshem while planning the PV design. Therefore, it is crucial to start a discussion with the Building permit department at an early stage of the process if the chosen building has a yellow or red mark in the building protection program.

The result of LCC analysis showed that the best case from an economical point of view was the Chinese panels Srp 320 with the biggest amount of savings and shortest payback time. This occurs due to the low price of the panels and lower price growth rate compared to the Polish panels. From the integration combined with a LCA points of view, the Polish panels should be implemented which have a worse performance in LCC analysis.

From three different system sizes, the best performance showed the system designed according to the annual energy use of the building. This occurred due to approximately the same amount of overproduction hours for both systems and the low price for the electricity sold to the grid. The battery implementation is not worth the investments due to the still high price and the need to replace it after 15 years. The smallest system showed the shortest payback period but at the same time the lowest amount of savings.

The study regarding the impact on the environment with LCA as well as the investigated transportation impacts showed that buying PV panels from a more local producer rather that importing them from China could make a difference on their environmental impact. Furthermore, the embodied energy of the product has to be taken into consideration and this can be done by demanding information from the manufacturing company.

7 Further strategies for Helsingborgshem

One scenario this study did not take into consideration was the possibility to involve the tenant’s electricity usage and potentially the surrounding buildings by having a joined subscription for the electricity. In this case the whole roof could be completely covered with integrated PV panels and none or only a small amount of electricity would be feed into the grid.

The market value of the building after implementing a PV system should potentially be higher compared to the same building with a regular roofing material. Not many studies has been made about this topic and if there is a difference between the integrated PV system compared to the regular installation of PV system.

8 Summary

Currently the humankind's total energy use consists of 87% of non-renewable energy sources. The government of Sweden is aiming for 100% renewable energy system by the year of 2040. The city of Helsingborg is now experiencing a solar panel expansion, the installed power increased with 139% from 2015 to 2016.

Nowadays a lot of focus is on the initial cost and payback time when implementing a Photovoltaic system on a roof of a building. Little attention is paid to the aesthetic and architectural integration and also the environmental impact of the embodied energy of PVs.

The objective of this thesis was to provide Helsingborgshem, a real-estate company in Helsingborg, with a list of their buildings together with a selection of those which are suitable for a PV implementation as well as a LCC and a LCA analysis. In total 89 addresses were considered initially. The results showed that 19 of the studied buildings were suitable for a solar system implementation, from an irradiation analysis as well as how likely the buildings where to receive a permission on the PV installations point of view. Three of these buildings from different areas were then selected to be studied further.

The hourly electricity usage data for the three buildings alongside with the future predicted usage was estimated and the BEN requirements for the electricity usage, which states what can be covered by the PVs when making an energy declaration, were fulfilled. Three different system sizes were considered in order to see the amount of overproduction with the possibility of selling it to the grid. A battery implementation was also considered for one of the buildings, the results showed that it was not profitable to add. Two manufactures of PVs from China and Poland were studied for the LCC and LCA analysis. The result showed that the best system design from a LCC point of view was the annual usage coverage system size with the Chinese panels. The LCA study of the transportations showed that the panels from Poland had a significantly lower amount of transportation emissions compared to the panels manufactured in China. The best integration possibilities from an aesthetic point of view were achieved with the Polish full black panels.

Overall, the results showed that in order to get the most profitable system, the Chinese panels should be selected but to get the least amount of emissions alongside with the most integrated system, the Polish panels were recommended.

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Appendices

A.

The list of investigated buildings can be seen in Table A1 and the irradiation map in Figure A2.

Table A1: The complete list of all the investigated buildings.

Address	Irradiation level	Permit possibility	Area / m²	Comments
Harlyckegatan 7	Very good	Likely	440	
Edwin Berlings gata 2	Very good	Likely	270	
Tyringegatan 292	Very good	Likely	102	
Liebäckskroken 2A, B	Very good	Unlikely	227	One building, a lot of vegetation in front
Liebäckskroken 2C-F	Very good	Unlikely	489	
Liebäckskroken 2G-H	Very good	Unlikely	218	
Harlyckegatan 3	Very good	Unlikely	439	
Liebäckskroken 3A-B	Very good	Unlikely	229	One building
Liebäckskroken 3C	Very good	Unlikely	138	
Jönköpingsgatan 37	Very good	Likely	270	Roof windows and chimneys
Jönköpingsgatan 39	Very good	Likely	270	Roof windows and chimneys
Jönköpingsgatan 41	Very good	Likely	273	Roof windows and chimneys
Edwin Berlings gata 8	Very good	Likely	270	
Jönköpingsgatan 52 (a)	Very good	Possibly	314	One part of three on the same address
Jönköpingsgatan 54 (a)	Very good	Possibly	421	One part of three on the same address
Jönköpingsgatan 56 (a)	Very good	Possibly	317	One part of three on the same address
Åhusgatan 1 (a)	Very good	Possibly	123	One building
Åhusgatan 1 (b)	Very good	Possibly	229	
Karlskronagatan 2	Very good	Possibly	122	One building
Lundagatan 7 & 9	Very good	Possibly	227	
Åhusgatan 6	Very good	Possibly	486	
Blekingegatan 22	Very good	Possibly	278	
Kristianstadsgatan 25	Very good	Possibly	39	Small building
Skånegatan 50	Very good	Possibly	258	

Address	**Irradiation level**	**Permit possibility**	**Area / m²**	**Comments**
Örebrogatan 4	Very good	Possibly	133	One building
Örebrogatan 6	Very good	Possibly	130	
Örebrogatan 8	Very good	Possibly	129	
Örebrogatan 10	Very good	Possibly	129	
Örebrogatan 12	Very good	Possibly	127	
Örebrogatan 14	Very good	Possibly	136	
Tyringegatan 2	Very good	Likely	102	
Tyringegatan 4	Very good	Likely	102	
Tyringegatan 6	Very good	Likely	104	
Tyringegatan 70	Very good	Likely	105	
Tyringegatan 72	Very good	Likely	105	
Tyringegatan 74	Very good	Likely	101	
Tyringegatan 294	Very good	Likely	102	
Tyringegatan 296	Very good	Likely	102	
Tyringegatan 298	Very good	Likely	102	
Nedre Holländaregatan 24	Very good	Likely	98	
Gustav Adolfs Gata 12	Very good	Likely	96	
Gasverksgatan 28B	Very good	Likely	97	
Tågagatan 48	Good, very good	Likely	28 ; 46	Roof windows and a small area
Liebäckskroken 4	Good	Unlikely	342	
Liebäckskroken 10A	Good	Unlikely	130	One building
Liebäckskroken 10B-D	Good	Unlikely	306	
Liebäckskroken 10E	Good	Unlikely	135	
Harlyckegatan 5	Good	Unlikely	534	
Harelyckegatan 9	Good	Unlikely	345	A lot of vegitation
Erik Dahlbergsgata 21&23	Good	Likely	255	
Edwin Berlings gata 4	Good	Likely	227	
Edwin Berlings gata 6	Good	Likely	218	
Jönköpingsgatan 52 (2)	Good	Possibly	87	One part of three on the same address
Jönköpingsgatan 52 (3)	Good	Possibly	28	One part of three on the same address
Jönköpingsgatan 54 (2)	Good	Possibly	86	One part of three on the same address
Jönköpingsgatan 54 (3)	Good	Possibly	28	One part of three on the same address

Address	**Irradiation level**	**Permit possibility**	**Area / m²**	**Comments**
Jönköpingsgatan 56 (2)	Good	Possibly	89	One part of three on the same address
Jönköpingsgatan 56 (3)	Good	Possibly	28	One part of three on the same address
Örebrogatan 2	Good	Possibly	333	
Åhusgatan 5 & 7	Good	Possibly	227	
Blekingegatan 31	Good	Possibly	211	
Jönköpingsgatan 24	Good	Possibly	334	
Jönköpingsgatan 26	Good	Possibly	331	
Nedre Holländaregatan 26	Good	Likely	194	
Nedre Holländaregatan 28	Good	Likely	139	
Gustav Adolfs Gata 10	Good	Likely	144; 196	
Gasverksgatan 28A	Good	Likely	290	
Gasverksgatan 30A	Good	Likely	145	
Gasverksgatan 30B	Good	Likely	103	
Tyringegatan 8	Reasonable	Likely	146 ; 103	Roof windows on the East side
Tyringegatan 10	Unsuitable - Reasonable	Likely		A small building between 8 & 12
Tyringegatan 12	Unsuitable - Reasonable	Likely		
Tyringegatan 194	Unsuitable - Reasonable	Likely		
Tyringegatan 196	Unsuitable - Reasonable	Likely		
Tyringegatan 198	Unsuitable - Reasonable	Likely		
Tyringegatan 200	Unsuitable - Reasonable	Likely		
Tyringegatan 202	Unsuitable - Reasonable	Likely		
Tyringegatan 206	Unsuitable - Reasonable	Likely		
Tyringegatan 208	Unsuitable - Reasonable	Likely		
Tyringegatan 354	Unsuitable - Reasonable	Likely		Roof windows on the East side
Tyringegatan 356	Unsuitable - Reasonable	Likely		Roof windows on the East side

Address	Irradiation level	Permit possibility	Area / m²	Comments
Liebäckskroken 6	Unsuitable	Likely		Newly built building, with solar collectors
Liebäckskroken 8	Unsuitable	Likely		Newly built building, with solar panels
Vaktgatan 1	Unsuitable	Likely		Flat roof and a lot of shading from AHUs on the roof
Vaktgatan 3	Unsuitable	Likely		Flat roof and a lot of shading from AHUs on the roof

Figure A2: The final irradiation map of Helsingborg with all the addresses and limitations.

B.

The complete hourly data can be seen in Figure B1-B6.

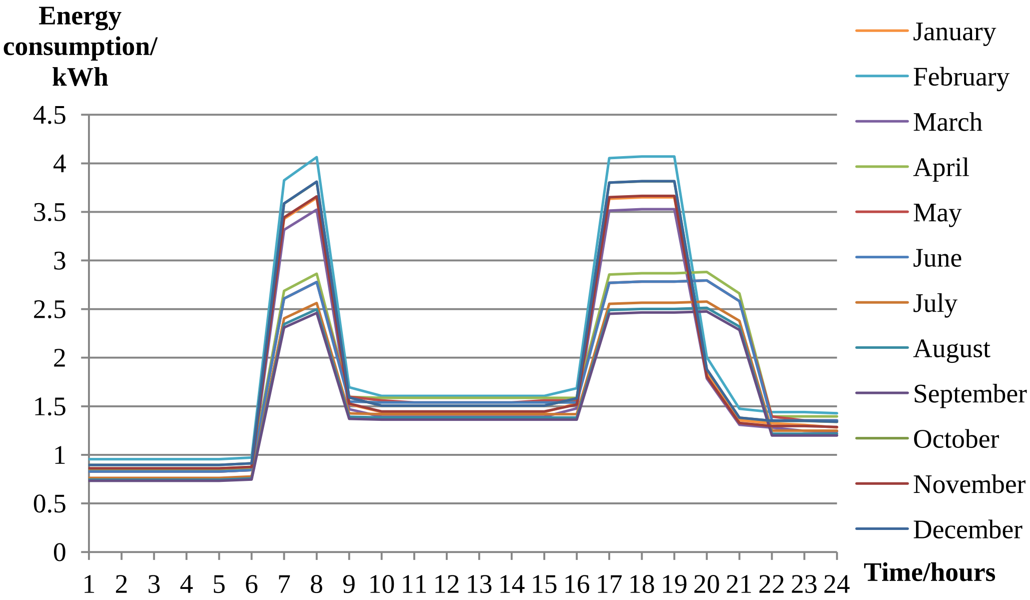

Figure B1: Hourly data for weekdays, Edwin Berlings gata 2.

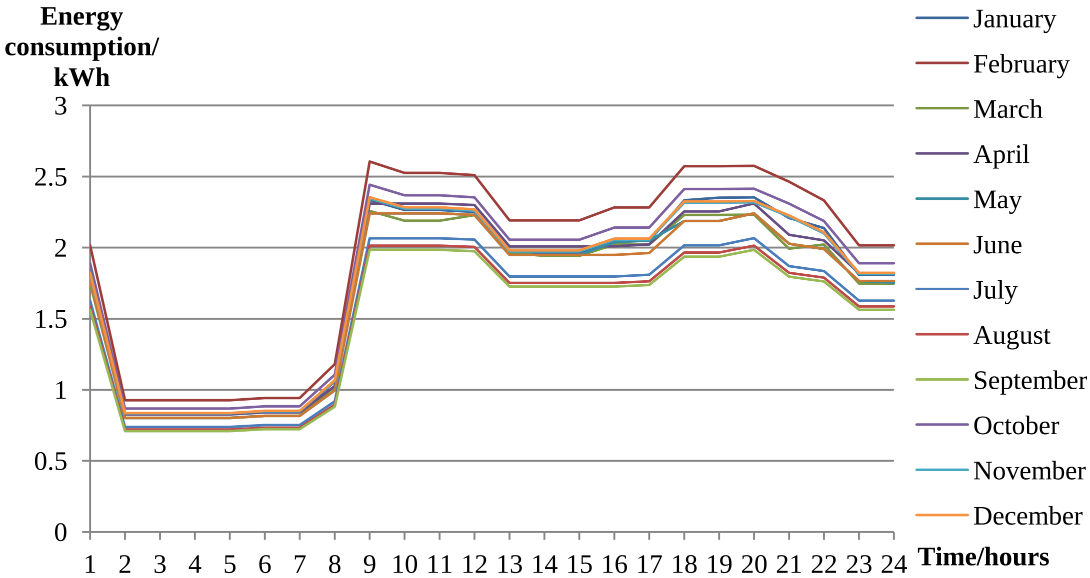

Figure B2: Hourly data for weekends, Edwin Berlings gata 2.

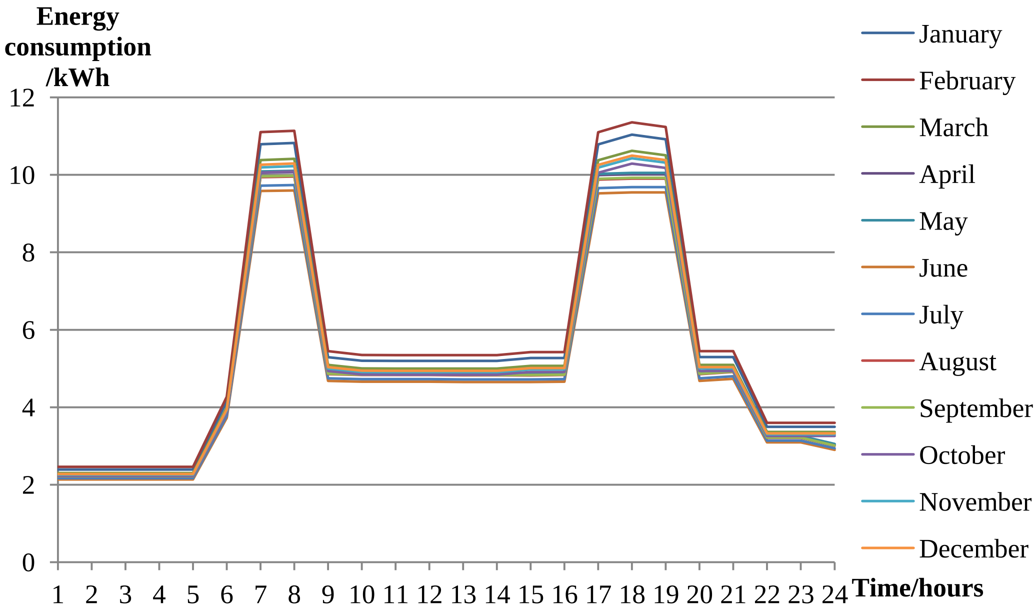

Figure B3: Hourly data for weekdays, Harlyckegatan 7.

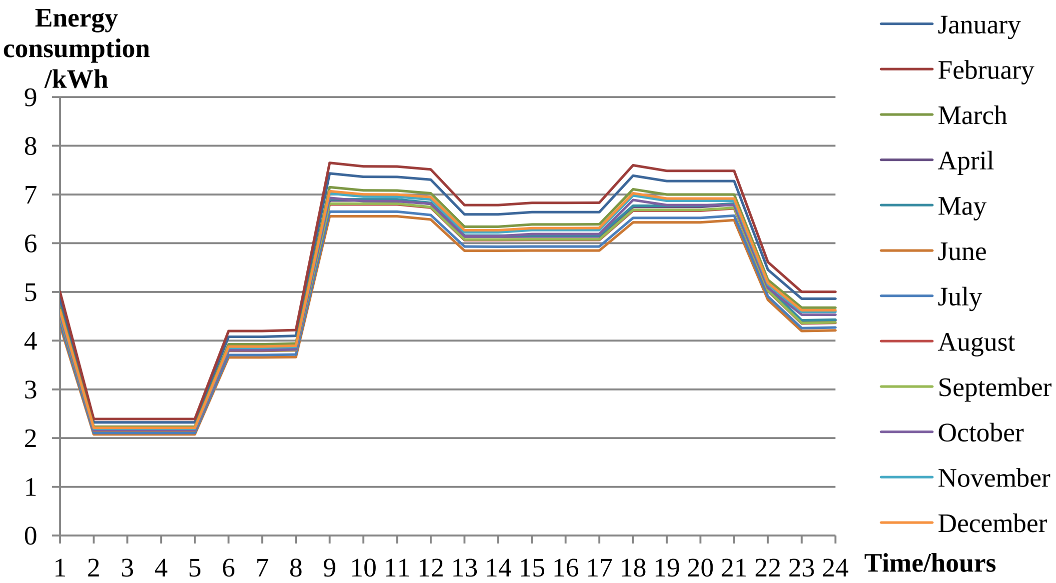

Figure B4: Hourly data for weekends, Harlyckegatan 7.

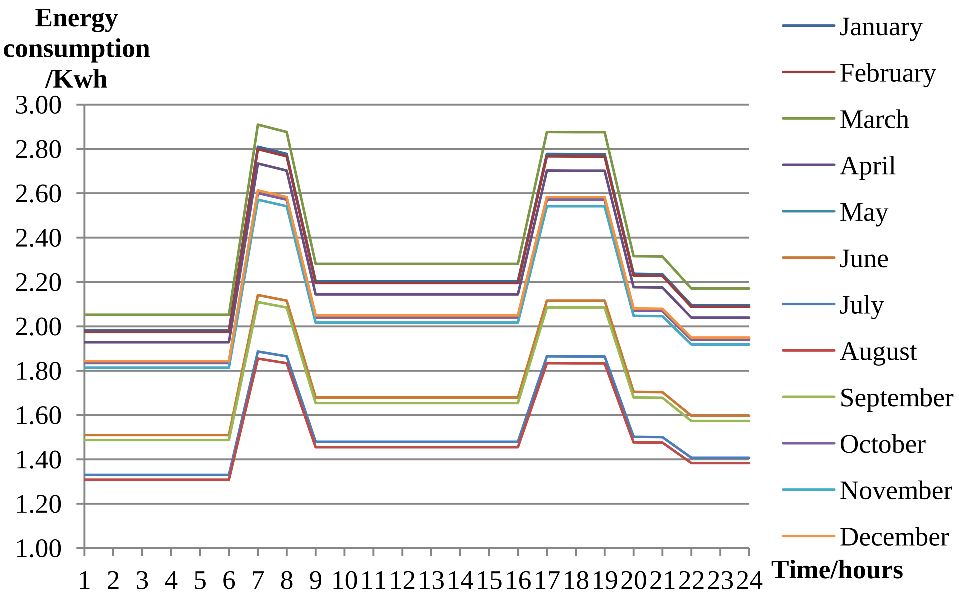

Figure B5: Hourly data for weekdays, Tyringegatan 292.

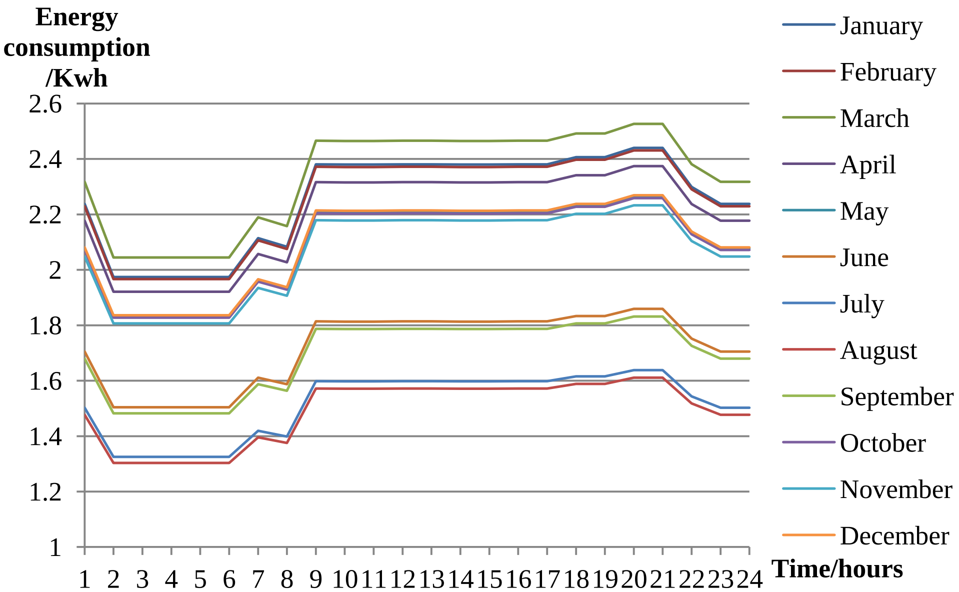

Figure B6: Hourly data for weekends, Tyringegatan 292.

C.

The LCC results for all the investigated system designs for Edwin Berlings gata 2, Future case 2 can be seen in the Figures C1-C3 and Table C1.

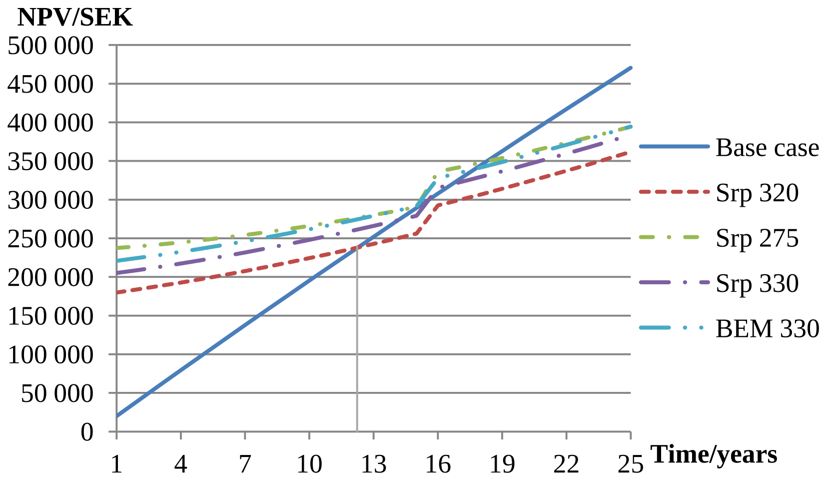

Figure C1: The LCC analysis results for the case of 33.7 kWp system.

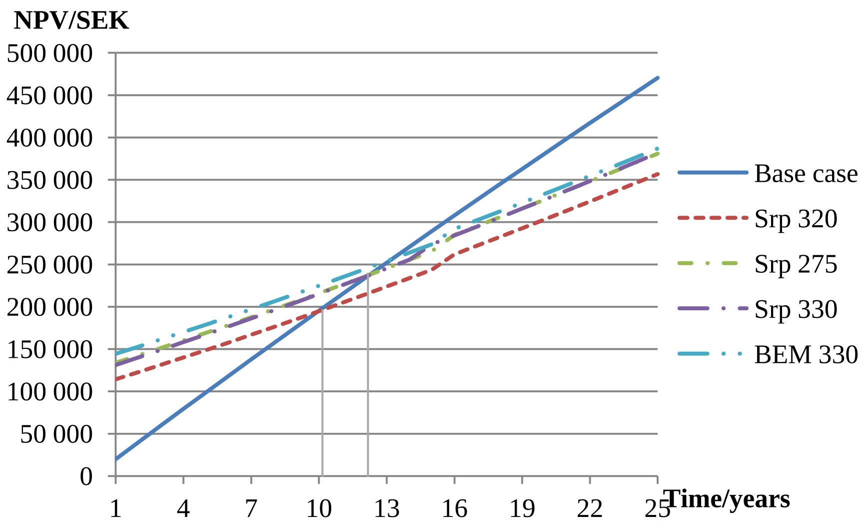

Figure C2: The LCC analysis for the 22.5 kWp system.

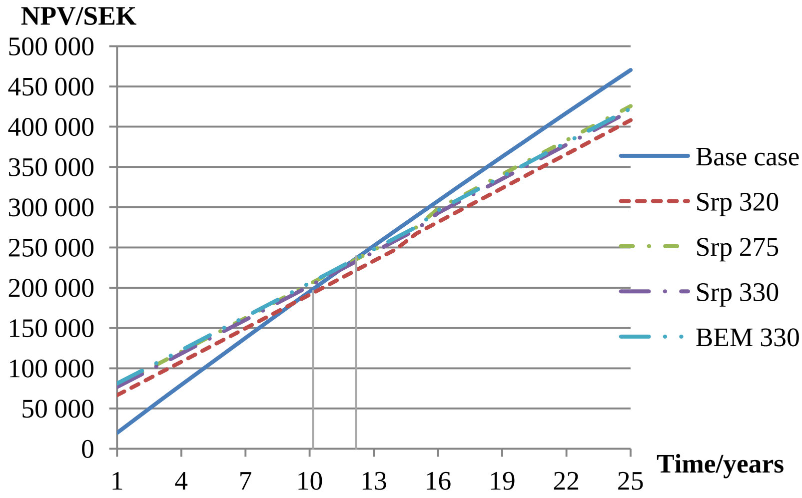

Figure C3: The LCC analysis for the 13 kWp system.

Total savings and payback period for all the systems can be seen in the Table C1.

Table C1: Total savings and payback period for the Future case 2.

	Total savings/SEK				Payback period/years			
System size/kWp	Srp 320	Srp 275	Srp 330	BEM 330	Srp 320	Srp 275	Srp 330	BEM 330
33.7	108 747	76 147	86 783	75 899	13	19	17	18
22.5	113 607	89 528	88 774	83 418	10	13	13	14
13	62 347	44 831	50 546	47 861	10	12	12	13

D.

The LCC results for Harlyckegatan 7, Future case 2 for all the investigated system sizes and panels can be seen in the Figures D1-D3 and Table D1.

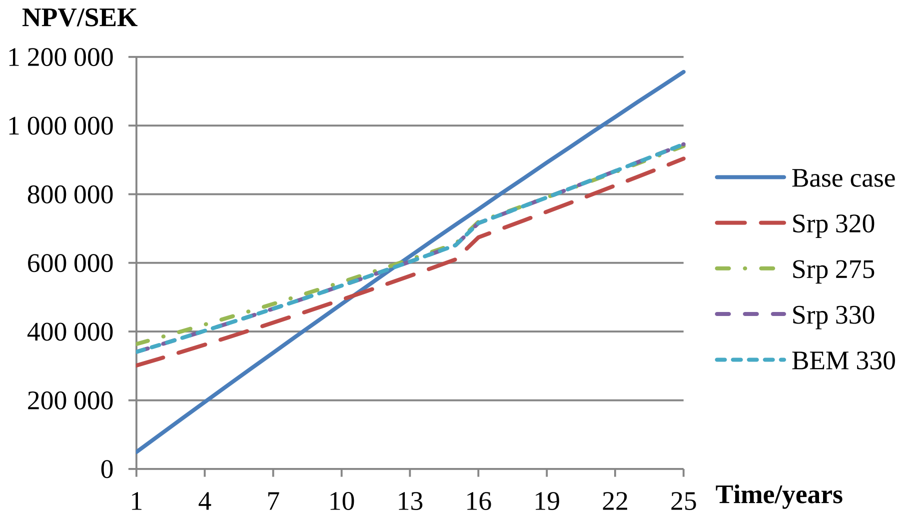

Figure D1: The LCC analysis for the 56 kWp system

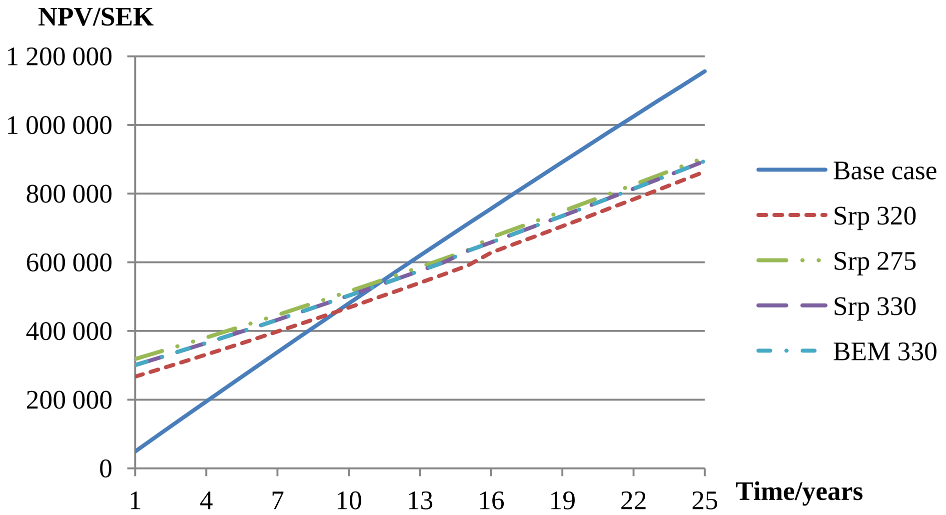

Figure D2: The LCC analysis for the 55 kWp system.

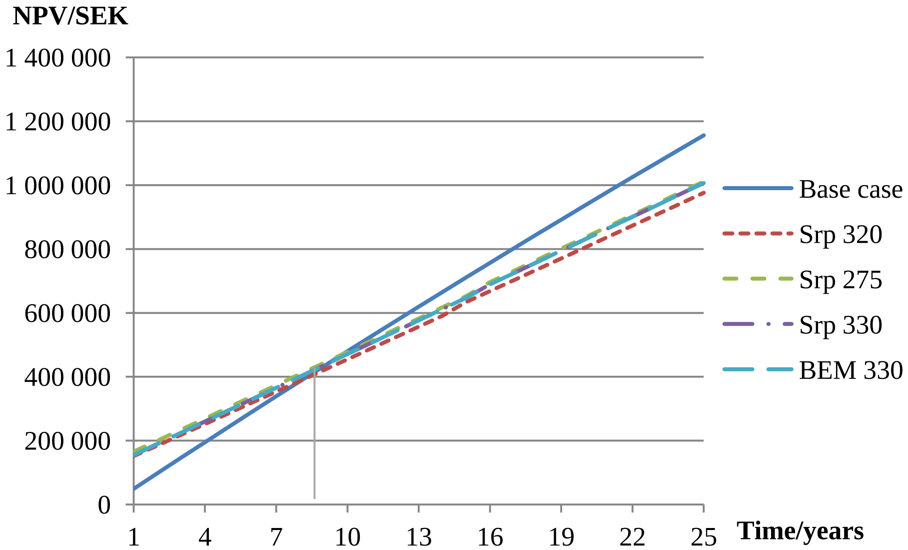

Figure D3: The LCC analysis for the 23 kWp system.

In Table D1 the results of the total savings and payback period is presented.

Table D1: Results for the total savings and payback time.

	Total savings/SEK				Payback time/years			
System size/kWp	Srp 320	Srp 275	Srp 330	BEM 330	Srp 320	Srp 275	Srp 330	BEM 330
56	252 578	215 678	210 365	190 707	11	13	13	14
55	292 199	250 953	261 538	228 261	10	12	12	13
23	180 349	145 016	149 614	127 478	9	10	10	12

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