Degree Thesis

Master's Program in Energy Smart Innovation in the Built Environment, 180 credits

Application of Colored Solar Panels on Municipal buildings in Sweden-

The multiple benefits for an Innovative Renewable Society

Master Thesis in Engineering Construction, 30 credits

Halmstad 2021-05-26
Safaa Aqel

HALMSTAD UNIVERSITY

MASTER'S DEGREE
FINAL DISSERTATION

Application of Colored Solar Panels on Municipal buildings in Sweden - The multiple benefits for an Innovative Renewable Society

Safaa Hadil Aqel

Supervisor: John Lindgren
Thesis in Construction Engineering with specialization in Renewable Energy 30HP

HÖGSKOLAN I HALMSTAD

Halmstad University
Halmstad, May 2021

Abstract

The purpose of this report is to understand how and why the diffusion of colored solar panels take place. A motive for the study is the fact that Sweden needs to reach the goal of a fossil free country by 2045, with one of the sub-goals of solar power contributing to 10 percent of the renewable energy production. Currently, Sweden's electricity production is only at 0.1 percent solar power. I have found that the innovation of colored solar panels could be a factor to contribute to the diffusion and increase in solar power.

To analyze this hypothesis, two different methods were used. First, a literature study was conducted where the focus was on the history and diffusion of solar panels, in correlation to the fundamentals of colored solar panels. I also compared the two technologies regarding their efficiency and price, as well as how they differentiate in the market. Second, an interview study was conducted with 17 solar experts working in different cities across Sweden. The experts had different insights to bring from their different positions in the solar power industry. The results showed that standard and colored solar panels are highly interrelated, causing the colored solar panels to always be slightly less efficient than the standard module.

The results also suggest that there is a high potential for colored solar panels in the future, and that there is a high need for marketing and reliable companies in order for the diffusion to happen. A major affecting factor for the diffusion of colored solar panels is architects, who have a large input in the design process of municipal buildings. Further research is needed in the development in the standard and colored module, as well as in the stability of colored solar panel companies.

Abbreviations

BIPV = Building Integrated Photovoltaics

PV = Photovoltaics

Si = Silicon

c-Si = Crystalline silicon

mc-Si = Polycrystalline silicon

Table of contents

1. Introduction

1.1 Background

Sweden is one of the most progressing countries regarding the change towards the innovation of a renewable energy world. The Swedish government has a goal set to 2045, stating that the country will be fossil-free. This is a major topic of discussion, not only in Sweden, but globally. Large impacts are constantly being put on the environment with the high Co2 emissions due to, for example, nuclear power plants (Dahlgren, Kanda & Anderberg, 2019). In Sweden, year 2019, 39% of the total electricity production was from nuclear power (Holmström, 2020), which is a high percentage that needs to be lowered, making the topic of sustainability and renewable energy very relevant (Dahlgren, Kanda & Anderberg, 2019). According to research on solar energy (Vattenfall, 2019), stating that if all Swedish villas were provided with solar panels on their roofs, it would accumulate approximately 8% of Sweden's electricity demand. However, solar panels have not been the first choice for electricity for many people. Looking at the past 10 years of solar panel history and implementation, we can see that the application of solar panels has increased every year. But, not in the pace of its potential in comparison with other countries (which will be presented later in the report), due to several hurdles regarding different aspects of the solar panel system. First, the aesthetics have been shown as displeasing, according to different research on people's thoughts on solar panels. There is also a stigma on solar panels being very expensive, and not worth the investment, as well as not being energy efficient, all of these hindering the system to grow (Vattenfall, 2019).

These reasons sheds light on colored solar panels as an alternative. The aspect of having an efficient, yet colored and aesthetically pleasing solar panel, is creating a way for solar panels to reach new markets and attract customers (Karlsson, 2019). A concrete example of colored solar panels is on a parking garage in the city Linköping, Sweden. This building has become a parking garage known for its beautiful aesthetics, while at the same time has been able to power charging stations for electric cars, as well as lowering the operating costs for the building. It is estimated to, with the implementation of the colored solar panels, lower Co2 emissions by 750kg per year (Soltech, 2016). This shows that colored solar panels are useful and might be needed for the push for development on this renewable energy system, especially with its high potential for aesthetic reasons regarding different color options. For this to happen, more research needs to be conducted, and therefore there is a need for this thesis that will build on the research on colored solar panels.

1.2 Objective

Colored solar panels are not common in today's society, since there is insufficient information on using them, which has led to major misconceptions and obstacles around the topic, one being the aesthetic perspective (Glasbranschföreningen, 2019). By comprehending the diffusion process of standard solar panels, and their similarities and differences with colored solar panels, an understanding could be built on the diffusion process of both standard and colored solar panels.

Hence, the purpose of this thesis is to first gather applicable, relevant data on solar panels, as well as the similarities and differences between standard and colored solar panels. From this basis, collect information on the diffusion process on solar panels, both in Sweden and internationally, and the surrounding influencing factors for this. By creating an understanding on standard solar panels, colored solar panels can also be understood. By also focusing on the potential and the application of colored solar panels on municipality buildings, a larger market for the system could potentially be seen and show what aspects are needed for the diffusion of the innovation. This will then give a clearer comprehension of the potential and benefits of colored solar panels, which in turn, will act as a base for further research and development. To specify the objective, the report will answer the following research questions:

1. How does colored and uncolored solar panels affect the energy efficiency of the electricity production long-term?
2. What benefits would the application of solar panels on municipality buildings in Sweden bring, and how do colored solar panels bring additional value?
3. What is needed for the diffusion of colored solar panels to bring benefits on a local and national level in Sweden?
4. What characterizes the diffusion process of colored and uncolored solar panels?

1.3 Research Approach

This report will be made up of two parts. One part will be a literature study consisting of available information gathered from solar panel research on both colored and uncolored panels. Searching electronic databases, such as Halmstad Högskola OneSearch, will provide literature that can be reviewed and combined. This, together with other relevant internet sources will be the base for the literature study, which in turn, can be correlated to the empirical part of the report. The empirical study will consist of data gathered from different colored solar panel companies around Sweden, and possibly also Denmark since they might have more advanced data on the objective in question. Interviews with specialists in the subject, will be conducted in order to gain insight of the different benefits and potentials. This data will be analyzed through different dimensions from the so known Pettigrew and Whipp model, which will organize the information for it to be be understood from a change perspective, especially for the questions on the diffusion of the innovation. Pettigrew and Whipp have created a framework in which to guide their own research regarding strategy and organizational change. The focus of the framework is the fact that strategic change is not a random occurrence, rather, a highly intercorrelated process to the organization. Strategic change is seen to be joint with competition, as well as occurring on different levels at different times of the change. This can be seen through a holistic point of view, meaning, a firm is linked with aspects on a firm level, but also with the firm as a whole, the sector of topic, and on a national and international level. To understand the strategic change, three dimensions are necessary to describe: content, context, and process. These dimensions have a back-and-forth effect on each other, which is what creates the process of change which can be analyzed through the dimensions (Pettigrew & Whip, 1993). Therefore, in researching any change process all three dimensions should be investigated. I have hence used this framework as a structure for developing my understanding of colored solar panels on a deeper level.

The dimension of content is about what changes are to be made. This is important in order to start a process, accordingly, knowing the objectives of the change strategy, the target and target price, as well as the effectiveness of the topic. The context dimension focuses on the pressures from an internal and external environment. This could be pressures and motivators such as economical aspects; business drivers, management decisions, business competition, or other environmental factors; culture, politics, and social aspects. Lastly, the process dimension reflects on the methodology of planning and evaluation (Pettigrew & Whip, 1993). Further on in this thesis, these three dimensions will be used to analyze the literature study under the three categories “Content”, “Context” and “Process”, as well as be an underlying structure throughout the report.

1.4 Implementation of solar panels

The first solar panels were discovered in the 1800s, where the efficiency was less than 1%. However, solar panels did not have good efficiency and they were expensive. In 1957, the efficiency of solar panels began to increase. The efficiency came up to 8% and in 1985 the efficiency was up to 20% and a cost at 105 SEK/watt (Han, 2014). The solar Panel technology has evolved at a rapid pace and that made manufactures be able to create solar panels with an efficiency up to 22%. In addition to solar panel efficiency increasing dramatically, solar panel producers have significantly improved their manufacturing process and that resulted in price decreasing dramatically, down to 24 SEK/ watt in 2021(Matasci, 2021).

There are many factors for why solar panels become implemented. One factor is that the world is in trouble of running out of fossil fuel and environmentalists will eventually have their way with dams. Another factor is the high cost of the energy. There began to be focus on how to save the world with renewable energy and the governmens and policies began to get involved and adopt comprehensive police framework to support renewable energy (Gallagher, 2013). In 2012, Sweden participated in European solar days, where the focus was on increasing interest in and knowledge about solar energy (Offerman, 2012).

2 Solar panels

2.1 Solar panel technology in Sweden

Solar panels in Sweden can be said to have their starting point in 1992, when they started to be installed, but not until 2006 was the major breakthrough where 300 kW was installed for that year alone (Ahrberg, 2021). Up to 2006 there were hardly any grid connected photovoltaic systems, whereas the off grid installed capacity was around 4.30 MW (International Energy Agency, 2019). After that starting point, photovoltaic systems were installed annually in order to maintain the development and growth of the Swedish solar sector. As of today, the most recent statistics show that year 2020 had a total of 66.000 grid-connected photovoltaic systems. This corresponds to a total grid-power of 1089 MW and off-grid of 15.82 MW (International Energy Agency, 2019 & Ahrberg, 2021). More specifically, figure 1 and 2 shows the number of the grid-connected installations and the installed effect, from 2016 to 2020. The figures are distributed in three categories, ranging from installations lower than 20 kW to higher than 1000 kW. As seen in both figures, solar panel installations are increasing each year. The installed efficiency is also increasing rapidly, where it increased with 65% in 2017, 78% in 2018, 70% in 2019 and 56 % in 2020 (Energimyndigheten, 2020). The majority of the installed power from 2020 is coming from facilities under 20kW, meaning smaller facilities such as rooftops of a villa or house. These growths are more seen in larger cities in Sweden, including Gothenburg, Stockholm, and Linköping (Energimyndigheten, 2020).

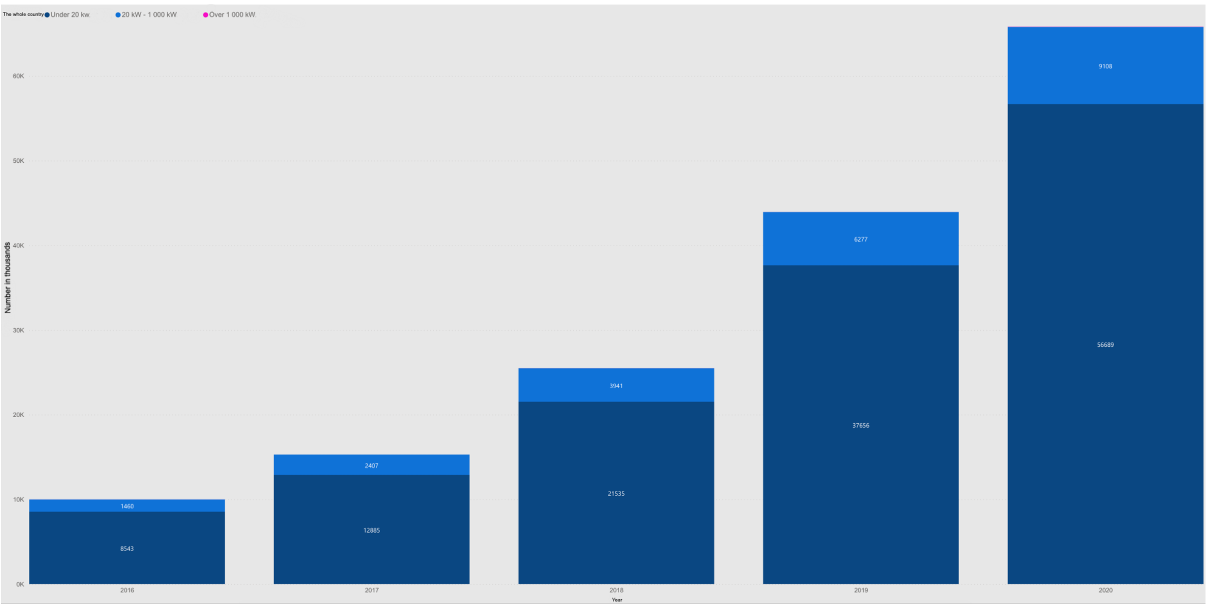

Figure 1: Number of grid-connected solar panel installations from 2016 to 2020 (SCB, 2020)

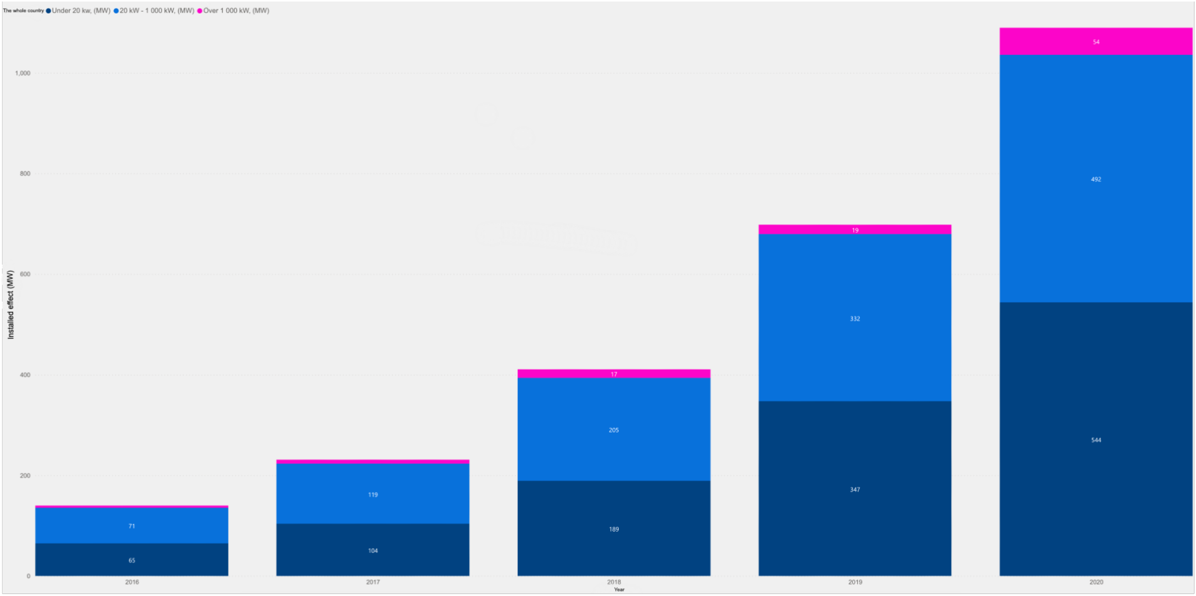

Figure 2: The installed solar panel effect from 2016 to 2020 (SCB, 2020)

The installation growth was done in an indigenous matter. There were no feed-in-tariffs to push the development, rather individual homeowners, municipalities, farmers, and companies were the investors. Around half of the solar panels installed are on residential systems and half on commercial facilities. (Lindahl & Stoltz, 2019). A growth such as this, has made it possible for the Swedish solar market to lower the price of solar power, with an 80% decrease in the last 7 years. In turn, investing in solar panels has been made affordable for private individuals (Ahrberg, 2021).

2.1.2 Solar panel concerns

Sweden has sunny summers, while also having very dark winters, creating the illusion of not being suitable for developing their solar panel technology. However, the Swedish meteorological and hydrological institute (SMHI) has had stations to measure solar radiation, since the 1980s. These stations track the weather prognosis and show the potential of solar energy through the information they bring on solar radiation (SMHI, 2021). Statistics show that, since 2011 to 2019, Sweden has had a total of over 2000 hours of solar radiation per year. More specifically, a colder month, such as December, had approximately 34 hours of sun in 2019 (SMHI, 2019). Further on, statistics for the month of July, has since 2011 to 2019, had an average of around 300 hours of sun (SMHI, 2019). An overview of the solar radiation for the whole year in Sweden, hence shows, that there is several hours of sunlight that is present throughout the country. As the Swedish Society for Nature Conservation (SSNC) then says, Sweden may not be the sunniest country, but it is sunny enough for installing and benefiting on solar panels. Moreover, SSNC (Naturskyddsföreningen, 2021) makes the comparison that southern Sweden has the same solar radiation as northern Germany, which is the world's most solar panel dense country. Also, Denmark, which is the neighboring country of Sweden, but also much smaller in surface, has seven times more solar panels than Sweden itself (Naturskyddsföreningen, 2021).

Renewable sources are seen as unreliable on their own, because of their constant fluctuating factors, however, a change in perspective would help show the importance (Mathiesen et al., 2015). No technology will be the standalone solution for a fossil-free country. Neither solar panels, wind turbines, nor hydropower plants could produce electricity for the whole country since there is such high demands. Instead, all usable technologies, such as solar panels, need to be not only developed, but implemented and diffused in order to create a country that enables all appropriate renewable energy sources to be used (Naturskyddsföreningen, 2021).

2.1.3 ROT tax deduction

Sweden has had investment support for solar cells since 2005, where the support was first only for public buildings. Investment support has varied greatly from year to year as new rules and changes emerge from the government. The aid was very large from the beginning, as the aid could amount to 70% of the eligible costs (Notisum, 2006). That support lasted until 2008 and then the support began to be phased out. Each year since 2009, the government allocated a budget (see Table 1) for investment support for people to invest in solar panels, a sum which is then distributed in turn for those who have had their application approved, this sum varies from year to year (Solcellspriser, 2020). When installing solar panels, an application is sent in and needs to be approved to be able to get the support. However, this money runs out due to the great interest of installing solar panels (SvenskSolenergi, 2016). In 2012, a new type of support came out which is called ROT- deduction. You could either apply for an investment support or a ROT- deduction. If you apply for an investment support, the application is sent to the County Administrative Board, which administers and approves the application.

Now, looking at 2020, the investment support was provided to 20% of the installation cost of the solar panels. Every year, the state allocates a total amount of investment support. When the total amount has been paid out, applications remain in a queue for next year. For ROT-deduction, the deduction was 30% of the labor cost for the installation of solar panels and the Swedish tax Agency approves a standard of 30% of the total price (which gives a 9% actual deduction from the total price). The maximum amount for ROT-deduction is 50 000 Swedish crowns per person and the deduction is made on the invoice, which makes it easy for clients. It is more profitable to apply for an investment support, but it can take a lot of time, where in 2020, it was 18 000 applications in the queue, while for ROT-deduction, the money is removed directly from the invoice (Solcellspriser, 2020).

In January 2021, a new green ROT-deduction came into place, meaning a private person will be provided a 15% tax deduction on the installation of solar panels on their house (see Table 2) and 49 % for a solar cell battery. The company that installs the solar panels will deduct 15% of the cost before handing the invoice to the customer, and the company will afterwards receive a payment from the Swedish tax authorities. The highest amount deduction according to this regulation is 50.000 Swedish crowns per person and year. Also, as a solar panel owner in Sweden, a person can receive payment from leftover electricity that has been produced. A person is entitled to a tax reduction of 0.6 Swedish crowns per kWh of leftover electricity (Eonenergy, 2021).

Table 1: Annual budget for investment support (Solcellspriser, 2020)

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
95 millions	59 millions	59 millions	58 millions	153 millions	58 millions	90 millions	316 millions	586 millions	1085 millions	915 millions	1115 millions

Table 2: Level of ROT-tax deduction since 2011 (Bülow, 2021a)

Year	Size of the support
2021	15 %
2020-2019	20 %
2018-2017	30 %
2016-2015	30 % companies, 20 % others
2014-2013	35 %
2012	45 %
2011	55 % companies, 60 % others

2.1.4 Overview of the Solar Panel market Internationally

Understanding Sweden's progress and development in the solar panel market is put into perspective when seeing an overview of the global market. The International Energy Agency (2020a) has created the “IEA Photovoltaic Power Systems Programme” where a global collaboration is established to analyze solar energy and solar panels around the world. This was presented through a report which states that the PV market is growing. Previously, China was far ahead of every other country, with a total of 53 GW installed in 2017, to the most recent 30.1 GW in 2019. In 2017, the global PV marked reached 100 GW installed because of China accounting for a large percentage. Though, the market in China lowered throughout the 2 years, but the international market increased, which made the market hold its position over the 100 GW mark in 2017, 2018, and 2019 (International Energy Agency, 2020a). While China is the leading country in the PV market, it is followed by America that has an installed capacity of 13.3 GW. These two are part of the top 10 countries that represent 72% of the global annual PV market, together with the European countries Spain with 4.4 GW, Germany with 3.9 GW and Ukraine with 3.5 GW. The other five on the top 10 list are Asia-Pasific countries, India with 9.9 GW, Japan with 7 GW, Vietnam with 4.8 GW, Australia with 3.7 GW, and Korea with 3.1 GW installed capacity. Sweden has an installation of 287 MW, which is very small compared to the top 10 countries, however, it must be taken into consideration the size and population of the countries (International Energy Agency, 2020a).

The international installations of solar energy have in turn saved the planet on 720 tons of Co2 emissions. This reduced the global energy related emissions by 5.3% in 2019 (International Energy Agency, 2020a). The reason for the market growing is because of the increasing electricity demand and that solar panels are reducing in price and becoming more affordable. However, the International Energy Agency is highlighting that the PV market is being driven by the natural competitiveness of the industry, though, countries need to increase their efforts on the implementation to ensure that the market continues to grow (International Energy Agency, 2020b).

2.2 Solar panel materials

2.2.1 Solar panel production

The process of converting sunlight into energy through solar panels, can be understood when breaking down the process. Firstly, Bozkurt (2019) explains that solar panels are made up of the combination of solar cells. The solar cells inside the panel is what catches the sunlight (see Figure 3), and the sunlight can be seen as photons, which is the particle that turns into electrons by the solar cells. The electrons move around between the solar cells to combine each other and hence become a big electric current and voltage. The solar cells are able to do so since they are made of silicon, which is used as a semiconductor, meaning, the material conducts electricity (Bozkurt, 2019).

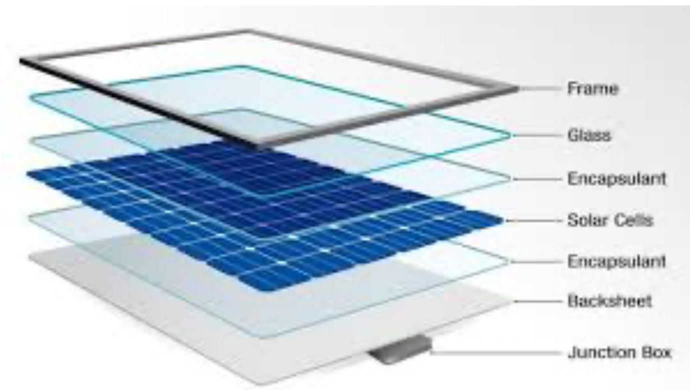

Figure 3: Layers of a solar panel (Solens Energi, n.d.)

2.2.2 Silicon (Si)

The commercial market for solar panels in Sweden, as well as globally, consists of crystalline silicon solar cells, where one of the major components is silicon as a semiconductor (Solens Energi, n.d.). The silicon must have a very high purity since it is the component that will absorb the sunlight. The crystalline silicon in a solar panel is hence directly interrelated with the panel's efficiency, which is why silicon has a long history of development in order to increase the efficiency of crystalline silicon solar panels (Tunahan, 2015). Silicon was first introduced as a semiconductor material in the 1950s, when the previously used material germanium did not hold up to standard. Silicon then was researched to have a greater potential for operating at elevated temperature, showing a current capability of 150 A. Silicon then replaced the place of germanium which only had a current capability of 35 A (Porst, 2004). The innovation of the silicon technology acted as the beginning of the 1950s silicon era. Silicon research and development moved rapidly during this time and was able to push the efficiency of the crystalline silicon solar panels up to 15% (Gul, Kotak & Muneer, 2016).

2.2.3 Crystalline silicon (c-Si) solar panels

The crystalline technology has a long history of research and development which shows its benefit in the commercial market, since the crystalline silicon solar panels have the highest module efficiency as of today (Solens Energi, n.d.). The silicon era was the start of the crystalline silicon solar panels push to the commercial market. Further on, in 1979, development continued and microelectronic technology advanced, benefiting the crystalline silicon solar cell efficiency which was raised from the previous 15% to 17% (Gul, Kotak & Muneer, 2016). As of today, the Swedish market offers crystalline silicon solar panels with an efficiency right above 21% (Wallnér, 2019), however, this has shown to not be the limit theoretically (see Figure 4).

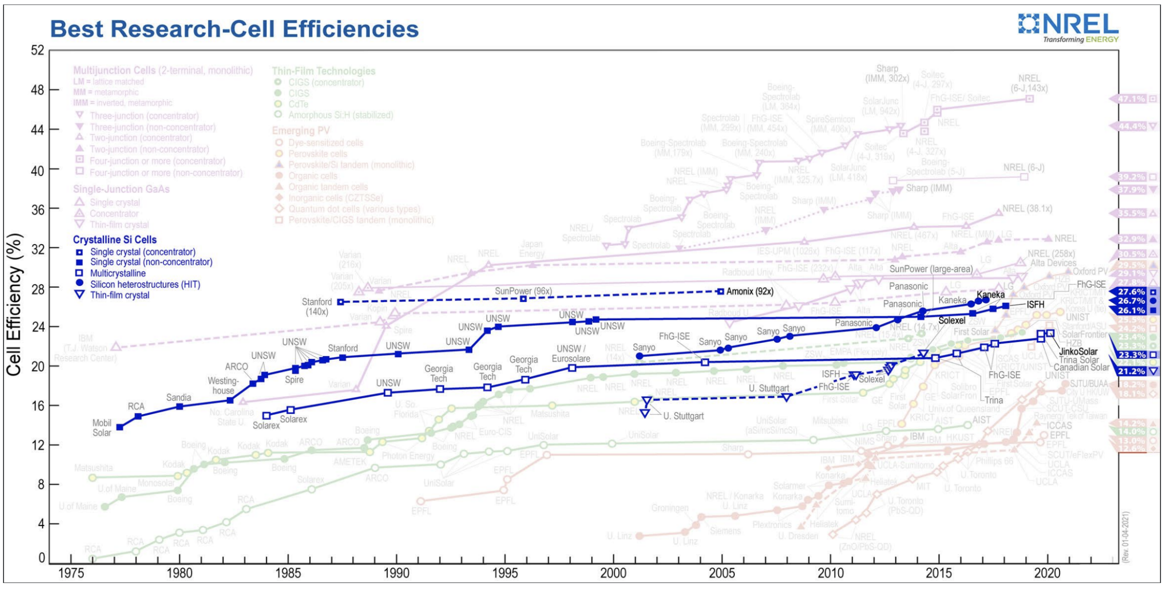

Figure 4: Highest efficiencies for crystalline silicon solar cells (NREL, 2020)

2.2.4 Monocrystalline silicon (c-Si) and Polycrystalline silicon (mc-Si)

Crystalline silicon solar panels are divided into two variations, which today can be seen as the black, alternatively dark-blue solar panels around the world. The standard dark-blue solar panels are what is known as polycrystalline silicon solar panels while monocrystalline silicon panels are the black modules (Solens Energi, n.d.). Monocrystalline solar panels (black) have an efficiency range of 16-20%. Polycrystalline or multi-crystalline solar modules (blue) are cheaper to manufacture than monocrystalline solar modules. They are also more preferred in the market and have a solar panel efficiency range of 15-16.9% (Gul, Kotak & Muneer, 2016).

2.3 Coloring solar panels

2.3.1 Printed, coated or alternative finished front glass

Colored solar panels can be printed, coated, or have a type of special finish on a piece of glass. These types of modules are produced by pairing a glass front sheet with a glass or metal back-sheet, with monocrystalline silicon cells in between. The front glass can be texturized to provide, for example, a shining or matte finish to the solar panel. The modification of the front glass naturally leads to changes in the optical behavior of the glass sheet, meaning it has a possibility to lower the efficiency of the panel (Pelle, et al., 2020). In the colored solar panel technology, two manufacturers are commercially known using printed, coated, and an alternative finished colored front glass. These two are copyrighted as Kromatix and ColorBlast.

2.3.1.1 Kromatix

SwissINSO is the creator of the solar innovation Kromatix, a colored glass used with solar panels on buildings around the world, including Germany, Denmark, Canada, Dubai, and Switzerland. Kromatix glass is a technology developed with the concept of using no paint, dyes, or tint to the glass in order to minimize transmittance loss and hence absorbing more of the available sunlight (SwissINSO, n.d.). Instead, this glass technology functions in a similar way to a morpho butterfly, which gets its color from interference (Kameleon Solar, n.d.). Interference is a process that creates colors based on a complex interaction between light and several optical processes. To understand the interference that creates the color in a natural occurrence, light needs to be seen as a wave. The light that comes from the sun, are waves that in the case of Kromatix, hit the glass, they align with the reflection caused from the glass and then create the bright colors which can be seen in different gradations (Kinoshita, Yoshioka & Miyazaki, 2008). When looking at a Kromatix solar panel from the front, it appears in the bright color it is, while when viewing it from a side angle, the color appears a lighter shade of that color. This iridescence effect is caused by the interference of light, thus, not using paint in the glass, and hence eliminating the factor of totally lowering the efficiency by having a color layer hindering the transmittance (Kameleon Solar, n.d.).

The Kromatix colored glass technology is highly customizable in regard to creating various sizes and thicknesses. The colored glass has the possibility to fit any size solar cells needed. SwissINSO manufactures stand-alone Kromatix glass for projects that want to fit these to their own solar cells, or SwissINSO can deliver a complete colored solar panel with the Kromatix glass which would provide a module efficiency ranging between 13,4 - 14,7% (see Table 3), which is around 75% - 90% of a standard solar panel manufactured in Sweden (SwissINSOa).

Table 3: Efficiency difference Kromatix colors vs standard black solar panel

Manufacturer	Color	Efficiency
Soltech	Black	20,1%
Kromatix	Bronze	14,7%
Kromatix	Green	14,7%
Kromatix	Orange	13,4%
Kromatix	Gold	13,4%
Kromatix	Brass	13,7%
Kromatix	Blue-green	14,4%

2.3.1.2 ColorBlast

Kameleon Solar is a Dutch manufacturer of colored solar panels and has created their own technology of so called ColorBlast solar panels. The ColorBlast technology is an optical illusion created by small colored dots on a glass surface. By covering the front glass of a solar panel with colored dots, it allows for light to pass through to the solar cells, where the empty space is. Since each dot has an empty space around it, light can be absorbed evenly across the panel surface. This also means that, where there is a dot, there is no transmittance through that dot. Hence, in order to generate more energy, less dots can be placed in order to not only let more light pass through, but also create a darker color. This technique of coloring is made by digitally printing a ceramic ink in a metric pattern on the frontside of the glass, and must be tempered in a hardening oven at a temperature of over 500°C. The high temperature allows for the ink to become as resistant as the glass itself, and hence, remaining colorfast for over 50 years. However, ColorBlast glass only works with a background that is one solid color. Most of the time, a standard solar panel is of a black color, and if combined with a white ColorBlast glass, will create the optical illusion of a grey color if installed on a building facade. This is due to the empty space which needs to be in place for the light to pass through. It also the reason why a ColorBlast color facade is best seen from a distance of approximately five meters. In comparison to the Kromatix technology, there are similarities, however, the manufacturing technologies are different as well as the factor of efficiency (see Table 4) (Kameleon Solar, n.d.2).

2.3.1.3 Semi-transparent and colored PV-active layers

Solar panels that have colored PV-active layers and are semi-transparent, depend on how colored the PV-active layer is. Colors can appear brighter or less transparent depending on the materials used or the type of dye that colored the active layer (Pelle, et al., 2020). This largely depends on the manufacturer, and a commercially available manufacturer of this type of solar panel is the Swedish company Soltech Energy.

2.3.1.4 Soltech Energy

Soltech Energy is a Swedish developer and manufacturer of colored solar panels, with a vision of making solar technology easily available. It is one of the largest manufacturers of solar panels in Sweden, and offer two colored technologies, Soltech Facade Color and Soltech Facade Semitransparent. Both of these colored facades are within the thin film technologies, where the Semitransparent Facade from Soltech, are Cadmium telluride (CdTe) solar cell, and the Color Facade are Copper indium gallium selenide (CIGS) solar cells (Soltech Energy, n.d.). In general, thin film technology means the manufacturing process of the solar panel has less or no silicon. One of the more efficient solar cells in the thin film technology, is CIGS, which because of its larger span of research and development has reached higher efficiency rates than CdTe. CdTe cells are formed from, as the name explains, cadmium, while CIGS is made by adding gallium to copped indium selenide (Gul, Kotak & Muneer, 2016). In the case of Soltech's colored solar panels, the transparent panels differ regarding efficiency, depending on how transparent the panels are, hence it being hard to put a number to the efficiency (see Table 4). The more transparent, the more light can be transmitted.

Table 4. Property differences between colored solar panel technologies

	Kromatix	ColorBlast	Soltech Color
Colors	6 types	Multiple	5 types
Color fastness	25 years	50+ years	
Weight	22.5 Kg per m2	22.5 Kg per m2	19,5 Kg per m2
Physics	c-Si	c-Si	Thinfilm, CIGS
Efficiency	13.4 - 14.7%	8 - 15%	
Output	80 - 150Wp/m2	80 - 150Wp/m2	93 - 120 W/m2

2.4 Standard versus colored solar panels

Comparing solar panels on a small-scale level, such as comparing solar panel efficiency per square meter, is not optimal. Solar panel projects are dependent on the quantity and the complexity of the project, as well as the material of the roof or other base material, and the inclination of the base for the solar panel (Kameleon Solar, 2021). Vattenfall (2021) provides a general overview of the price and effect of a solar panel installation on a house, however, they highlight that comparing solar panels are highly project dependent. For example, the more solar panels a person installs on their house, the lower the installation cost would be for that project. This can be seen when using Vattenfalls digital solar panel project calculator (see Table 5) (Vattenfall, 2021).

Table 5: Aspect differences when installing different amounts of solar panels

	Case 1	Case 2	Case 3
Solar panels	8 on 19 m2	30 on 64 m2	180 on 345 m2
Price	78.160 SEK	137.456 SEK	660.000 SEK
Produced el.	2.440 kWh/y.	9.290 kWh/y.	55.749 kWh/y.
Payback time	26 y., 3 m.	10 y., 4 m.	8 y., 9 m.

The minimum requirement in order to calculate a solar panel project via Vattenfall, is 8 solar panels, and a surface of 19 m². This shows that the payback time, meaning, the time in which a person would start earning money on the investment, in case 1 is a little over 26 years. According to Vattenfall (2021), the lifespan of an installed solar panel is 30 years. The average installation for solar panels is, as case 2 shows, 30 solar panels. This was the average installation by people in Sweden, year 2019 (Bülow, 2021b), showing a significantly lower payback time of 10 years and 4 months, compared to case 1.

2.4.1 Module prices

Thanks to the decline of prices of solar panels, it has led to more people installing them. Between 2008 and 2013 there was a sharp decline in price, when a standard solar panel of crystalline silicon module went down from 61 Swedish crowns/Wp to 8.9 Swedish crowns/Wp. This depended a lot on the international market that had a sharp development, most of all the Chinese market who had one of the highest peaks in the market between 2008 and 2013. Thus, the price has kept going down with the ongoing development of the solar panel market. From 2017 to 2018, the price was lowered by an additional 15%, and in 2019 it was down to 4.1 Swedish crowns/Wp (International Energy Agency, 2019). However, when looking to install solar panels as a private individual or a project, it is not possible to compare prices from solar panel websites. A specific number cannot be put on how much the solar cells will cost, since this is affected by many different factors. Companies can give out an estimate, but this is most likely to change when the project planning is complete (Vattenfall, 2011, personal communication). The most recognized and important factor for giving a price is the power of the installation. Normally, a price for a power with 30 kW is around 2 000 Swedish crowns per square meter. But the bigger an installation is, the more profitable the cost will be, meanwhile, you would also get more power per Swedish crown for larger solar cell systems. This is because the cost of driving out and assembling a protective scaffolding is largely the same regardless of the site of the facility. Another factor is that the cost of wiring between the solar cells and the inverter is also the same regardless of the size (HemSol, 2021). One more factor is the components will not increase in proportion to the size of the installation, an example is, a twice as powerful inverter does not mean double the price.

Furthermore, the design of the roof can be costly depending on the inclination of the roof and what type of roof it is. Lastly, a major factor is what type of solar cell is installed. As mentioned above, the most common today is the monocrystalline solar panels of about 320 watts because they are very affordable. HemSol (2021) highlights that if you want more aesthetically pleasing solar panels, people need to be ready that the investment may be higher than expected for the same power. Since colored solar panels are not commercially available in the market, the price can vary from different companies. A cost proposal for a colored solar panel project in Gothenburg called Friskväderstorget was introduced by both SolarLab and Megasol (see Table 6). There is also another polish company called MLSystem which has a lower price than both SolarLab and Megasol with more fire tests. There is still an ongoing test for these colored solar panels, so it is not clear how much the total power is. It will be a great benefit if the total power is approximately the same, but if not, it is more profitable to stick with SolarLAB (Elin Elmehag at AFRY, 2021, personal communication).

Table 6: Price proposal for Friskväderstorget in Gothenburg (Elin Elmehag at AFRY, 2021, personal communication)

	Company	**Number of solar panels**	**Watt per piece**	**Total power**	**Color**	**Price** **Swe Crowns/m2**
Option 1	Megasol	271 (1x1.67)	280 W/pc	75.88 kW (167 W/m2)	Dark green	5 300/m2
Option 2	SolarLAB	271 (1x1.67)	280 W/pc	75.88 kW (167 W/m2)	Dark green	4 000/m2
Option 3	SolarLAB	1300 (0.6x0.6)	45 W/pc	58.5 kW (125 W/m2)	Dark green	5 150/m2
Option 3	MLSystem	271 (1x1.67)	-	-	Bronze	2 643/m2

2.4.2 Installation of solar panels

The installation of solar panels is personalized to the house or building. Different buildings have different architectures and different materials on both their roof and facade, meaning there will be different fundamentals for the installations (Vattenfall, 2021, personal communication). Therefore, different mounts are available for where the solar panels will be attached. Most commonly, mounts are installed on the rafters of the roof, where the solar panel is attached and wired in (Eonenergy, 2021). However, if solar panels are installed on a roof, a quality control needs to be executed. If a roof is due for a renovation because of its age, it is not appropriate to install solar panels since the roof will need to be taken out after a short amount of time. It is therefore better to install solar panels on a new or relatively new roof that is known to last at least 30 more years, making the investment of installing solar panels profitable (Kameleon Solar, 2021, personal communication).

The installation process for standard solar panels and colored solar panels is the same (Vattenfall, 2021). A difference can be seen on building integrated photovoltaic systems (BIPV), where the solar panels are integrated into the building envelope. It hence does not use the same mountings as when installed on a roof. The solar panels would then instead become the roof or the facade, replacing the conventional building envelope materials and then being installed in a similar way to building the roof or facade (Strong, 2016). A renovation process can also become a BIPV system, for example, when a roof is old and needs to be changed before installing the solar panels. In this case, solar panels could be integrated in the roof, hence, saving time and money by removing the process of first changing the roof and then installing the panels (Strong, 2016).

When working with standard installations on roofs or the facade, as well as with BIPV systems, the placement of the solar panels needs to be put into consideration. If a solar panel is placed in an area where shadow will be what the panel is exposed to, then this will not produce any power. However, when placed where the sun is visible, the sun rays, in turn, must hit the panel vertically to produce as much power as possible. Though, much research has been made in order to find out the optimum tilt angle and orientation for solar panels in order to maximize the solar intake. The main conclusion has been the importance of the orientation being to the south since this is where the panel will be exposed to the most solar radiation (Mehleri et. al, 2010). This is also supported by Jamtkraft (2021), which state that to be able to reach the best efficiency for solar panels, the roof should have an inclination between 10-55 degrees and be directed in south, southwest, or southeast. Solar cells facing east also work well, but the efficiency will be a little lower. Figure 5 shows how the direction and inclination of the installed solar panel is affecting the efficiency. If the solar panels are installed on the roof with an inclination of 30 degrees facing south, then it will get a 100% efficiency. However, if the solar panels are installed to the south direction, on a facade, it will on a maximum get 71% efficiency from the sun. Jamkraft (2021) also mention that solar panels can produce energy even though it is cloudy, but shadows effect the energy production. (Jamtkraft, 2021).

	Direction of latitude				
Degrees	270° W	225° SW	180° S	135° SE	90° E
0°	90%	90%	90%	90%	90%
10°	89%	94%	96%	94%	90%
20°	87%	96%	98%	96%	88%
30°	86%	96%	100%	96%	86%
40°	82%	95%	100%	96%	84%
50°	78%	92%	97%	93%	80%
60°	74%	87%	93%	89%	76%
70°	69%	82%	87%	84%	70%
80°	63%	75%	80%	77%	65%
90°	56%	67%	71%	69%	58%

Figure 5: Percentage of solar panel efficiency depending on installed direction and inclination

2.5 Examples of colored solar panel projects

The advantages of colored solar panels are largely summarized on the aesthetic benefits. Colored solar panels offer many ways for architects to integrate the energy-saving panels with the layout of a house, which is shown on different buildings around the world (Kameleon Solar, 2021). Colored solar panels made a large first appearance in the public eye when one of the largest building integrated solar panel projects came to be. This is known as the Copenhagen International School (CIS) (see Figure 6), where a total of 12.000 colored solar panels were installed, covering the entirety of the building. The colored solar panels are of a blue-green hue which is one of the standard colors of the Kromatix glass technology. The glass has a satin finish and can appear to look different shades of the blue-green color when seen through different angles. The panels are tilted at a four-degree angle, in order for not only the facade to be ventilated, but in a design perspective to mimic the water of where the building is placed. The blue-green color in combination with the tilt creates a dynamic facade which the company in charge of the project, SolarLab, purposely made happen (Jolissaint, Habnali, Hadorn & Schüler, 2017).

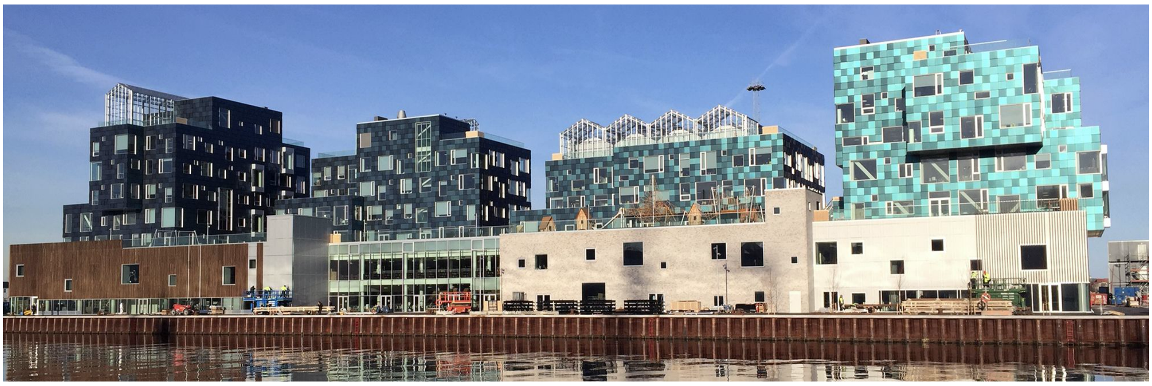

Figure 6: Colored solar panels on CIS (Solarlab, 2020)

Figure 7: Colored solar panels on a parking garage

In the city of Linköping, Sweden, a parking garage covered in colored solar panels was opened in 2020 (see Figure 7). The parking garage has a facade of 567 transparent colored solar panels, consisting of the colors blue, green, red, and orange (Kesselfors, 2017). This facade is helping the parking garage produce electricity for the 60 charging posts for electric cars that come to park in the garage. The use of the solar panels is producing enough electricity for the parking garage in Linköping to save 750 kg of carbon dioxide emissions per year (Soltech energy, n.d.). Similarly, the Festo building in southern Germany is saving the world of emissions by yearly producing 26 531 kWh/year, from their installed colored solar panels. The Festo building is a 67-meter-high construction, where the entire floor is covered in colored solar panels. The solar panels are grey from the Kromatix colors, and give a power of 33 kWp (Jolissaint, Habnali, Hadorn & Schüler, 2017). According to Rickard Viklund, manager for the project, each panel had 64W per panel and the total cost was approximately 800.000 Swedish crowns without the installation (Rickard Viklund, 2021, personal communication).

2.6 Considerations when installing solar panels

2.6.1 Building permit for solar cells

A building permit is needed when changing roofing materials, facade cladding or other external changes on a building that significantly affect its external appearance. This means that if you install solar panels on the roof or on the facade within a detailed planning area, a building permit is required. A detailed planned area is usually cities, communities, or the town, that have rules for changing the design and technical properties of this area. The society make requirements which are stated in the Planning and Building Act (PBL). The requirements for such areas and building within these areas are, for example, that the change of the solar cell installation entails must consider the cityscape and the building's aesthetic values and that it does not disturb the surroundings in an unacceptable way. The requirements for technical properties are, among other things, that a building with solar cells must meet the requirements for strength and fire protection. An installation of solar panels on a building is a change to the building and changes must, according to the legislation, be carried out carefully with regard to the building's characteristics and with the utilization of its cultural-historical values (Energimyndigheten, 2019). Some houses have a greater cultural-historical value. Sometimes they are called k-marked or q-marked. If a building has such marking, then more consideration must be taken when changing the characteristics of the building. What this means is specified by regulations that are in the detailed plan and can, for example, state what color a building may have or what the windows may look like (Stadsmuseet, 2020).

2.7 Previously highlighted influencing factors

In order to understand the broad background of the literature study above, an analysis of the theoretical frame of reference regarding the topic is needed. This chapter will hence describe three research articles and what these conclude on the diffusion of solar panels in Sweden.

About the local factors driving the diffusion of solar photovoltaics in Sweden, by Alvar Palm (2016), it is illustrated that five Swedish municipalities have driven themselves to a higher PV density compared to 50 other municipalities that were also studied. One large aspect discussed to be important, is the social aspects affecting the solar PV market. Through interviews, it could be seen that people locally, as well as municipalities, were socially influenced by each other at an early stage of the market. An example of this could be seen when a local company promoted PV systems by actively spreading information about the technology, as well as selling ready solar PV packages that only needed to be installed. This specific example showed the result of the PV market in this area starting to grow rapidly. However, it was highlighted that the base for such good growth had come from workers in the local company being well connected and established in the local social networks, which made them gain trust from customers, and push for the promotion of solar panels (Palm, 2016).

Jenny Palm and Elina Eriksson (2018) conducted a study where 58 households in Sweden were interviewed, between the course of 2013 and 2016, to gain an understanding of how people view solar panel installations. The interviews included a mix of adopters and non-adopters of PV systems, and the results showed that different measures were needed to meet the needs of different households. A main need for the non-adopters was information that is easily accessibly or understandable. Furthermore, information was needed from a higher third party, not including the PV company or other households that have a PV installation. This was seen to give the technology a higher reliability. Many of these factors were dependent on municipalities and PV companies having accurate and enough information to diffuse the technology (Palm & Eriksson, 2018).

In a research article on what drives home solar PV uptake in Sweden (Mundaca & Samahita, 2020), it could be concluded that Solar PV capacity has grown, however, its share in the power market is still very small. Previous literature has shown that the physical visibility of the technology has been of high importance, but on the contrary, the results from Mundaca and Samhita's study (2020) showed that the main factors for pushing the PV technology was subsidies and peer effects. Sweden has had high fluctuations in the governmental budgets and may fail to create investment conditions for solar PV systems in the long run. This could cause an insufficient capacity to promote the market and push for its growth (Mundaca & Samahita, 2020).

3 Analysis of the collected literature

The following analysis is the first of two analyses. The first analysis is on the literature study while the second is on the empirical study, both of which have been based on the framework of content, context, and process. This is the model that shows that a process or change is affected by external causes, in turn, the factor which guided the understanding of the literature study. Later in the report, the analysis will be discussed in correlation to the analysis of the empirical study.

3.1 Content analysis

To see the content of the solar panels is to see what is known about the topic, and what is needed to be understood in order to then see in what context these factors have been affected, to finally start the process of change. First off, the literature study showed very limited information on colored solar panels, which can be seen as a problem that needs change. When searching for reports, dissertations, and other material on colored solar panels, there was not any extensive research or information to be accessed. Not many reports have been written on the subject, hence, a lot of information had to be gathered directly from colored solar panel companies to get an understanding of the topic. For standard color panels, many more websites and reports were available to collect data, which shows the need for the change in making information on colored solar panels both more comprehensive, as well as available. Further on, when starting to write this report, the Swedish energy authorities had posted figures, showing the number of grid-connected installations and their installed effect, from 2016 to 2019. The increase was high each year, from 65% to 70%, and with the history of solar panels having a fast implementation, conclusions from this could be drawn that the high curve would continue. However, a few months later, a new figure was released for 2020, showing a 56% increase. Hence, it is important to keep track of the new information that is released, in order to have relevant statistics and facts about the subject. The content is always changing, meaning, that reading an information sheet on solar panels from 2015, could give misleading information in regard to finding out the potential. However, for understanding the history, older information has been of use, for example, when looking at how different subsidies for solar energy has changed throughout the years.

3.2 Context analysis

To see the context, the literature reviewed different context dimensions that has affected the solar panel industry over the years. From an environmental aspect, the literature shows that Sweden has made great progress over the years regarding implementing solar panels for a renewable society. Some cities, such as Halmstad, has had greater development, because of their management drivers within their municipality. A political aspect in the literature, was the subsidy changes over the years. This shows how Sweden has changed their rules on the help and subsidy that comes with installing solar panels, meaning the context for installing solar panels has changed yearly. From the international comparison, it can also be seen that a higher push from municipalities and help from subsidies and the government, has caused more installation and knowledge on solar panels, meaning the context is of great impact on the implementation. Moreover, a business and economical factor is the fact that there are not many suppliers of colored solar panels. This is also a context factor that makes the colored solar panel industry unreliable.

3.3 Process analysis

The process of change derives from both the content and context analysis, since these three are closely interrelated and dependent on each other. To know what needs to be changed, some insight could be gained by looking at the topic from an international perspective. Here, it could be seen that the focus in literature was not on how solar panels are manufactured in Sweden, since they are imported from countries where they already are developed. Though, the focus was on the different strategies' countries have made in order to expand the diffusion and implementation of solar panels in their country. One main difference is that Sweden only has one commercially marketed building with colored solar panels, namely Linköpings parking garage. Hence, it shows that the process of diffusing colored solar panels in Sweden has only just begun. Though, what is highly beneficial about colored solar panels, that brings much potential, it that the Kromatix colored glass technology is highly customizable, in regard to creating various sizes and thicknesses. The colored glass has the possibility to fit any size solar cells needed. This potential could bring the process of implementation forward since it has a base for fitting in with different settings.

As seen in the literature, solar panels and colored solar panels are interrelated, as are the factors surrounding them. The content is there because of the different context, and the many contexts is what is affecting the process of change. Understanding and working with these three categories of change, will create a basis for moving the innovation forward. Since colored solar panels is a relatively new innovation, there are not many companies working with colored solar panels. This context affects the content because of the few data there is to find about this technology since it is relatively new, and these two dimensions affects the process to drives further.

4 Method and Methodology

This chapter reflects on the method and methodology of this study. The methodology means understanding an entire research process and what affects it, while the method means the ways which were used to gather data (Neuman, 2014). In short, method could be described as how data is collected while methodology is why to collect data in a certain way. Hence, method and methodology are in many ways related to each other (Jackson II, Drummond & Camara, 2007). This chapter therefore aims to show awareness of both the method and methodology, and since these are closely linked and interdependent (Neuman, 2014), they will be discussed in close relation to each other.

4.1 Overview of the methods used

The literature study was created by searching for reports and research on the subject, through different literature search engines. The ones used was Halmstad Högskola Onesearch, Google Scholar, and ResearchGate. Keywords such as solar panels, solar panel materials, crystalline silicon, solar power internationally, and colored solar panels, were used as a base to find reports and research on the subject. The research found was also used to find further literature, by looking at the different reports' reference lists. The literature chosen was peer reviewed and as new as possible in order to keep the information reliable and relevant. This would ensure to keep a certain scientific quality in this thesis. Regarding the history of solar panels, older literature was used to see the changes throughout the years. Moreover, search words such as solar panels and colored solar panels were used on Google, to find the commercially marketed companies that show up. These could give relevant information on their website regarding the solar panels they have for sale, what the efficiency is, what panels and materials they use, and the warranty they offer. The thorough literature study was conducted prior to creating the interview questions to fully understand how solar panels work and what history they have, as well as how the future is planned. According to Adams (2015), interviewers need to be knowledgeable about the relevant issue and prepare for the interviews in order to gain relevant answers that can be analyzed.

A total of 17 sit-down interviews were conducted through the digital video conference service Microsoft Teams. The interviews that were conducted in this study were semi-structured interviews, meaning, there was a question appendix that was followed, however, follow-up questions were asked in order to obtain all possible relevant information from the interviewee (Adams, 2015). The people chosen for the interview were solar cell experts in different senses, either working in a company as a solar cell expert or being the chief executive officer for a solar cell company. To gain relevant insight for the purpose of this study, the people were purposefully chosen because they could provide knowledgeable answers. It is impossible to gather all information about a question, though, it is possible to uncover the information available and accessible at the time of the research (Jackson II, Drummond &

Camara, 2007). Therefore, the solar cell experts that were interviewed may not have had anything planned or do not know what will happen in the future. However, what they do know through their years of experience is what is happening now and what the potential for the innovation of colored solar panels is, which is the information and knowledge that is needed to build on the research and development on colored solar panels. By interviewing solar experts, the participants could give in-depth responses which is the basis for a qualitative research. This study is hence conducted in a qualitative manner where as much information on the subject is gathered, in order to understand something from different perspectives and compare this to what is known as facts through a literature study (Jackson II, Drummond & Camara, 2007).

Since this work is about interviewing different people and analyzing their answers, validity and reliability are an important concept in this study. This study is a qualitative study that is about being able to describe the collected and processed data in a systemic and "fairly" way. In order to compile all the information gathered from the interviews, all the interviews were recorded with consent from the interviewee verbally before starting the interview. The interviews could afterwards be transcribed through the recordings, meaning all the questions, supplementary questions, and answers were written down. Thinking noises and sounds used in the conversation to acknowledge the other person's answers, where not transcribed since a so-called edited transcription method was used. This means that all words are written down, however, not words connected to stuttering, repeat words, and thinking noises (Amberscript, 2021), since these were not seen as relevant to the study. The interviews were then color coded to easier connect answers within the same theme from the different people. The color categories were: solar cell industry, green; knowledge of colored solar panels, purple; production and manufacturing, yellow; materials, grey; environment, pink; subsidy and cost, red; potential of colored solar panels, blue; hurdles and problematics, orange. If a person mentioned or answered anything within one of these themes, it was highlighted with the specific color. Thus, when analyzing the answers, similar or contradicting answers, as well as different perspectives, within the same area, could easily be connected in a way to show how the answers support each other. The reason for not creating an analysis from the questions from each individual interview question is because the analysis would not be organized in a sense that it would not follow the framework of the report. Several of the interviewees could mention history, cost, subsidy, and future potential, meaning, including thoughts relating to all three framework categories content, context and process, in one answer. This would create an irrelevancy in the structure since it would not directly be connected to other interviewees answer, hence not show similarities and differences in a structured way.

Furthermore, the initial purpose of the literature study was to gather all relevant information about solar panels and colored solar panels, and their diffusion, in order to provide a picture of the solar panel technology and the market in Sweden. But by reviewing previous research from different reports and by contacting solar panel companies for more details on the modules available, as well as comparing the findings with itself and the survey and interviews, this study could switch focus to creating a deeper insight on the subject and development areas. This deeper insight was created by creating two separate analyses, the first following the literature study and hence being the literature analysis. The second following the interviews, being the interview analysis. The reason for creating two different chapters of analysis is for the reason the contents of the two studies have different prerequisites. While the literature study is based on the history of solar panels, the statistics, facts, as well as the available information on colored solar panels, the empirical study contains interview answers from different solar experts. The empirical study could be seen as subjective from the interviewee's perspective, where they reflect on their thoughts and experiences in correlation to known facts and information. Hence, an objective perspective could be seen from the literature study, where peer reviewed reports, and other information from company websites and projects is presented. The second analysis will be followed by a final discussion, where the two analyses, thus the two studies, will be compared and discussed. This will show how the interviews and literature are connected.

5 Interviews

In this chapter, the interview results will be presented. Three main themes were recognized through the 17 interviews, which will be presented in different sections. The main sections are "the recognition of the solar panel market", "the potential of colored solar panels", and "the diffusion of the innovation". These main themes were derived in correlation to the framework of content, context, and process. The content can generally be described through the recognition of the solar panel market, the context is described through the potential of colored solar panels, and the process is seen through the diffusion of the innovation. However, since the content, context, and process are three interrelated themes, aspects of the framework could be seen throughout the whole chapter, hence the reason of creating three more subject-specific categories for the chapter that instead include the framework subliminally.

The people interviewed will be presented with their full name as well as their position in the solar energy sector, since it will show what these highly educated or/and experienced people of solar energy think with their answers. In turn, giving the perspective on the topic that the standard person most likely does not know or see, which will both eliminate preconceptions that might exist as well as emphasize other hurdles or difficulties that need to be seen for the research and development of colored solar panels.

5.1 The recognition of the solar panel market

The solar cell industry, in general, is recognized as a good industry for the future. This is seen through all people interviewed saying that the market will develop in the right direction when asked how they think the industry will look like in Sweden in the next 10 years. However, they explained different perspectives and reasons for their assumptions about the future. Bernard Ranke is a solar cell expert at Solexperterna Värmland AB since 2014 and works with the whole process of getting in contact with the customer, calculating the offers, building the solar panel area of choice, and lastly putting it in operation where it is handed to the customer. As he says, it is hard to know exactly what will happen in 10 years' time, however:

"*It is hard to see 10 years ahead, but if you look 10 years back, it has happened incredibly much. [...] The development ahead will feature many new actors emerging and many new ideas, making it a much more established sector in 10 years. Already, there are educations within the sector, solar cell installers, which create standards on how to build a solar cell plant.*"

- Bernard Ranke.

The same thought process can be seen with property manager at Halmstad University, Rikard Ahlgren, who sees a bright future for solar panels because of their bright past. Throughout the years, solar panels have become more efficient as well as lowered in price. The more they develop the better the price will be, considering more customers investing in the technology and the market expanding. Though, many of the interviewed consider the current price of solar panels to be affordable, and hence not seeing the price lowering anymore in the future. Anders Elmqvist has some concrete experience on the pricing of solar panels. He is a project manager for renewable energy in the city of Malmö and since 2017 the motivation for installing solar panels was pushed when they noticed that they profited on it. Previously they did not follow up on the solar cell projects they did, since they knew it was a loss, they mostly did it for show. Through this experience, Anders came to see that costs change throughout time, and so do regulations, regarding taxes and so on. However, the more people invest in solar panels in the future, the more profitable it will be.

Furthermore, Bernard mentions both positive and negative aspects for the solar panel technology:

> "*The biggest positive aspect about solar panels is lowering your own energy cost, and in a broader perspective lowering the Co2 emissions that would have been emitted if produced with a nuclear power plant. Though, a drawback is that the manufacturing process of solar panels is that some of the materials are not very common, and that then leaking out in nature would not be very good for the environment. This is an aspect that the industry needs to work on.*"
>
> - Bernard Ranke

In the panel production stage, substances such as acids, fluorine, nitrogen oxide, and other solvents are present. These could be hazardous for the people in the building or if the substances were to leak out in nature. However, as with any production and manufacturing process, with standard safety protocols, the hazardous factors become very much controllable (Mahajan, 2012).

CEO of Aktiv Sol in Nöbbele AB, Bernth Nyberg, said that he indeed thinks the solar panel industry will increase little by little since he sees no disadvantages with them. He highlights that the advantages of solar panels will increase with time since we will get a power subscription for the household, meaning we must pay a fast annual fee to access the electricity grid based on the size of the meter fuse. This size will minimize if the household has solar panels which shows advantages for the future. Paula Björk, an energy and climate advisor in Malmö, who lectures on solar panels for companies and apartment buildings and housing associations, mentioned the same thing as CEO Bernth. She says that in a year or two, most suppliers will work with power subscriptions. In her words, it means that it will be more expensive to use energy. But by having solar panels you will be able to lower the power peaks that happen when people, for example, come home from work. Though, as Rikard Berg, energy and sustainability manager at Sigtuna municipality, highlights, the placement of the solar panels are important. If you have the panels on the wall, you will be able to have the highest effect early fall, in September, when the sun is at its lowest. But during the summer you will have the highest effect on the roof when the sun is the highest, needing the panels placed on the roof instead of the wall. It is hence about combining these two in order to get effect and energy during as much time of the year as possible. As Rikard Berg puts it "*We are bad at that today, they are only placed on the roof.*" Since the roof is the most common placement for solar panels in Sweden, many of the interviewees mentioned the condition of the roof. More specifically, Elin Elmehag, who is a solar cell consultant at AFRY, said that as long as you have a roof that is good then your investment will pay off. For example, if your whole roof is leaning towards north, if there is a lot of shadow covering your house, if your roof is divided into many small areas facing different directions, or if there is a chimney and other parts on the roof that would make the application of panels hard, then it is not a good investment.

Moreover, Paula Björk believes that the development of solar panels lies in a storage unit. Here you can save your solar energy which you can use instead of buying, so-called, dirty energy:

"*I think that in 10 years' time we will have reasonable prices for storage units for a homeowner. At present, they are quite expensive and not so profitable for a homeowner, so there will be a very nice storage unit, charging box and load balancing all in one, so you can keep track of your different phases and have a smart home."*

- Paula Björk

Mats Danielsson, also an energy and climate advisor, however, in Gothenburg, shares a lot of thoughts similar to Paula Björk. He also highlights the future of selling solar panels in a package with a charging box and a battery pack, and that the prices for especially the storage will be lowered in the future. The similar thoughts can be reflected upon both Paula and Mats being energy and climate advisors, hence having a set of questions they ask customers and knowledge they have gained to provide correct and similar answers to people who call in. These types of advisors are located in different cities throughout Sweden, in order to make it accessible for people to get help on questions or ask about investing in, in this case, solar panels. The counseling is based on the location and circumstances of specific cases, and this whole operation is funded by the Swedish government through the Swedish Energy Agency (Energimyndigheten, 2019). In a way, this showcases what some of the focal points regarding solar panels for the future, the government has, such as the insight on a solar panel package that both Paula and Mats highlighted as a next step for the industry.

5.2 Municipality perspective

To gain insight in a municipal perspective, operations engineer in technology and property management, Sven-Ingvar Petersson, provided insight on Halmstad municipality. He has control over the investment budget for solar panels each year for Halmstad and has also been in charge of several solar panel projects throughout his working years. Through his thoughts, everything is pointing straight up for the solar panel industry in Sweden:

"*I would think that in 10 years we will still have an upswing. We are so far behind than the rest of Europe and the world, so we need more than 10 years to catch up. I think there will be more ready-made packages and the efficiency will rise further. We have gone from when I started 10 years ago, we were maybe at 260-270 Watts per panel, and now the last ones we bought were at 370 Watts, and the price is down to a third of what it was before. I do not think the price will fall any more but definitely that the efficiency will rise further.*"

- Sven-Ingvar Petersson

Halmstad is one of the cities in Sweden that has implemented solar panels the most, out of all the cities in Sweden. A person such as Sven-Ingvar, believes in solar panels for the future, hence has a lot of influence on the city and the solar panel sector while working with the municipality. This can be seen through another municipal perspective from Bernard Ranke. Bernard illustrates what power the people working in the municipality has for different investments and developments:

"*As long as there is no person that works in a municipality who believes that solar cells are something to invest in, then there is no purpose for municipalities to invest in solar cells either. If they had a property engineer for example who is responsible for roofs in the municipalities or responsible for energy in the entire municipality and has experience of solar cells, then things would change. He will include it in the procurement idea when it comes to changing roofs and at the same time invest in solar cells. But as long as there are no people who think that solar cells are something to invest in, then municipalities as an organization will not come to think by themself, wow, what a smart idea to invest in solar cells!*"

- Bernard Ranke

Halmstad municipality received a solar energy award (Solenergipriset) in 2014. This is an annual reward for a specific construction, area, or in this case municipality who is seen as a good solar heat or solar power constructions that can inspire others (Svensk Solenergi, 2021). What was special about the 2014 reward, is that Halmstad received it for their long-term hard work with solar power, starting in 2009 where Halmstad invested a total of about 90 million Swedish crowns in the so known energy saving project (Energisparprojektet, EPC). Not only did they install solar panels on several schools, a large arena, an art museum, and much more, but as the jury handing out the reward described "[...] *they have created excellent opportunities to increase knowledge on solar power for future generations.*" (Halmstad kommun, 2014). Even though large buildings, such as a museum or university, can be an expensive investment to cover in solar panels, Anna Werner, CEO at Svensk Solenergi has a different input on the matter. Large investments might be expensive for a municipality, however, these investments are profitable and create value when looking at the marketing. She says that 80% of the inhabitants in Sweden want to invest in solar energy. If they then see that companies and the municipalities are doing this, it will create a positive snowball effect. As Paula Björk also mentions, it is tax money that is used for the installations that municipalities do, so they try to make sure that it is financed in a good way.

5.3 The potential of colored solar panels

A question in the interviews was if the person sees any potential for colored solar panels in the future, where the answers showed both potential and hurdles. While many of the interviewed were positive towards colored solar panels in different ways, their first response showcased something else. Lars Åbom, installer of renewable energy at Agronola Energy in Lundby, said that he has not heard much about colored solar panels. However, he himself says that this is because colored solar panels are not commercially available in the market. Colored solar panels are a relatively new technology, and companies always want what is available in the market, what is the cheapest option, even if the cheaper option is only a matter of a few Swedish crowns. When asked what the next step is for the colored solar panel market, a lot of focus was put on the design process with architects as well as marketing:

"*It has not been heard of [...]. I think they [colored solar panel companies] should reach out to famous architects and ask them to draw and design a house where the panels melt in with the color in relation to the color on the walls. So, you get something appealing [...]. I think that there can be very many solar panels in some places, it is not appealing.*"

- Lars Åbom

Many architects will find that the different options of colored solar panels are useful for new constructions and buildings, where they can be integrated and create an aesthetic look. Colored solar panels also offer different sets of transparency which can be used for different purposes. Pernilla Widstam, energy and climate advisor in Halmstad, says that the colored solar panels can be used as a shading device since you can look through it, but at the same time it captures the sun. In the same sense, Rikard Berg emphasizes that solar panels act as protection on the roof, especially on old buildings where there is no isolation on the roof. The sun does then not hit the roof in the same way, and acts as an isolation itself. In the same way, colored solar panels, which can often be installed on walls, have the same effect on the facade of the house, as an extra isolation on the building.

CEO and owner of Alfa Solvind in Skåne, Jonas Lundberg, says he has heard about colored solar panels but that the problem is the higher cost and lower effectiveness compared to standard solar panels. Though, he sees potential and a need for marketing, exhibitions, and advertisement on the colored solar panels. As of today, colored solar panels are not as available on internet as standard color panels. This makes it easier for customers to find regular solar panels, hence not knowing that colored solar panels even exist. In Jonas Lundbergs perspective, many people do not find standard solar panels good-looking which in many cases stops them from investing. He says that people might want solar panels that match the color of their roof, and this could be accomplishable through different colored solar panels. Furthermore, Sven-Ingvar Petersson also highlights the importance of marketing. If colored solar panels are not seen, and we cannot see anyone who is selling them, then there will be no one buying them either. Colored solar panel companies need to keep marketing themselves and informing solar cell consultants about the innovation. Solar cell consultants often work towards municipal real estate companies, and these often have more freedom regarding trying something new or developing an area. Elin Elmehag has solar panels at her own house and has a lot of experience with different customers who have different requests and wishes for mixed projects. She says that private real estate companies have higher demands on the profits and are not as risk-taking, and therefore highlights that there is more opportunity that municipalities will catch on and invest in something. She herself knows about colored solar panels and sees a large potential, which is why she proposes these in projects where they are fitting:

"*In many cases it has been the only way to get a building permit, either having colored solar panels or nothing at all. We wanted something nice and cool and then it does not matter if it costs a bit more. [...] If we were to create an art piece for the project instead of solar panels, it would have been expensive and not provide any electricity. So, we do not have to limit ourselves to the energy budget when installing colored solar panels, it is also for marketing purposes.*"

- Elin Elmehag

Paula Björk has a lot of knowledge on different circumstances for when customers call in and want to install solar panels, what their options are, the positives and the hinders. Hence, she pointed out that colored solar panels have a lot of potential for the future, especially regarding places where you are not allowed a building permit. This is something that Elin Elmehag has first-hand experience of, showing that colored solar panels indeed can be allowed in areas that have restrictions for building permits:

"*We have quite many [colored solar panel] projects, even some larger projects where we discuss with the architects what the best solution is for the property. I write a lot of cost proposals, so for a school in Gothenburg that is being rebuilt, it is within a detailed planning process that says that the roofs must be red. We then came up with choosing red roof tiles with integrated colored solar panels in the color red, in order to get the building permit. They would not have approved the building permit if we had standard solar panels.*"

- Elin Elmehag

Many places in Sweden do not allow for changing of the appearance of the area, so, if all houses in that area has a red roof, then a person cannot change their roof to a blue color. This also means that the standard blue or black solar panels would not be allowed in that specific area. However, a colored solar panel that has the ability to match the color or pattern of the roof would have a chance to be accepted in an area. The same concept is emphasized by Lars Åbom in the case of so known k-marked areas or buildings, such as churches and museums:

"*I have had a lot of contact with the church of Sweden. They have several churches that consume a lot of energy and most of them are located in an east-west direction, with a roof to the south as well as in most cases a superb and large roof. In these cases, the churches often want to install solar panels. However, the churches have been there since the 1100s, so they will decline the proposal since it is k-market, meaning it is forbidden to change the building. Though, if we say that we have panels that have the same color as the roof, they could agree to installing these. Here we have a market for colored solar panels.*"

- Lars Åbom

Petter Sjöström, project developer of solar cell systems and owner of Solkompaniet, as well as Mats Danielsson, also mention the potential of colored solar panels for k-marked areas, saying that there are buildings that cannot be changed however one likes. With colored solar panels, people interested in solar panels within these k-marked areas would have the opportunity to invest and benefit from the energy they would produce, such as with the churches that use a lot of electricity. As of today, this has not been conducted in a larger sense. Petter Sjöström says that he has made project proposals for k-marked areas, but that the people have not been satisfied with the price and therefore stopped the design process.

Paula Björk also highlights that colored solar panels have the ability to create a positive view on solar panels in general:

"*When it is to be installed in the cities, we want to continue to have a positive view on solar panels. Therefore, it is very important to have colored solar panels as well, because they are more aesthetically appealing and if you only use standard solar cells in cities, which are not very nice in appearance, the general image of solar cells and the popularity will be reduced. It is very important, if we want to reach the numbers that many municipalities have as a goal, then an enormous number of solar panels need to be built. [...] It is very important that you get different types of solar cells, everything possible really, glass, the nice colors. We should not underestimate that part of how much it means to people in architecture, incredibly important.*"

- Paula Björk

As seen in their answers, many of the interviewees mention municipalities as a focus for colored solar panels. Bernard Ranke expresses it as "*For larger commercial buildings there is definitely potential for colored solar panels, but maybe not in the same aspect for small houses.*". Larger commercial buildings could also be seen as municipal buildings, since these are the ones with large budgets and with a goal of representing the municipality, representing renewable energy and sustainability, which gives more purpose for investing in something such as colored solar panels, more than to a private person in a small house.

Colored solar panels are a relatively new technology, that will need a lot of development in order to achieve its full potential. However, all the interviewees had in common that they thought both colored and standard solar panels should be developed simultaneously. When comparing standard solar panels to colored ones, it is easy to picture that there can only be one. Though, this is not the case, because as many of the solar experts pointed out, to get many solar panels out to the world, options can only be helpful. More varieties of solar panels also fit different areas of application, accommodating to more people and customers. Hence, the solar energy market should continuously focus on both technologies. Anna Werner, however, says that she thinks both technologies should be of focus, but that this is not something that we should decide. What technology is in focus is decided by companies, they know what they want to focus on, what is in need of developing and what they have a will to invest in. As it seems as of today, the will to develop colored solar panels is growing, and with the higher need for sustainability and green energy, it is becoming a technology with high potential. The important question is then not whether to focus on developing standard or colored solar panels and in what order, rather, embrace that they are both needed for the solar industry. Petter Sjöström makes the important note that colored solar panels are in many cases dependent on standard solar panels:

"*With colored panels, it is about finding a new manufacturing technology, a new way to make them, that is cheaper. Because the colored glass that is off now is not going to get cheaper than it already is, and even if the efficiency is improved it would still be the same in relation to the standard solar panels.*"

- Petter Sjöström

Many colored solar panels are standard solar cells with a glass panel in front. The glass is then what minimizes the panel efficiency and will then always be less efficient than the standard solar panel which has no extra glass front. As Elin Elmhag formulates is, those who manufacture standard solar panels often do not manufacture colored solar panels. So, the standard solar panel manufacturers focus on getting the efficiency up and the manufacturers for the colored panels can work on marketing their technology. However, the colored solar panel manufacturers also buy the standard cells to create their panels, so when the efficiency of standard panels increases, the colored panels follow. The two are then not working against each other, rather, they are dependent on each other. The question then is if colored solar panels will ever be as efficient as the standard panels. Anders Elmqvist explains in detail why he thinks that the efficiency of standard solar panels will not get any better in the near future:

"*When photons hit solar cells, it needs a certain amount of energy to make the photons move. When it moves it goes over to the next solar cell and the same procedure happens there. Blue photons have more energy than what is needed, but this extra energy only heats up the solar cells, it cannot be used. How much energy photons need to become moveable and move around in the solar cell, this is the amount of energy that decides how much energy you get* *later. So, if photons have more energy, it does not matter. [...] So I do not know how much the efficiency will be raised. It is not that easy to raise it over the 22-24% we have today, because then physics comes and puts its boundaries on the traditional solar panels.*"

- Anders Elmqvist

In correlation to what Petter Sjöström said, Anders also thinks that solar panels need to be developed in a new way since the traditional way seems to not get much better. In other words, this means that colored solar panels cannot get more efficient than the standard ones, if they were not to be manufactured in a new way.

There are different colored solar panel companies showing up and stating they have a different way of manufacturing their colored panel, but there is not a large commercially marketed company that is known worldwide. As Petter Sjöström points out, the companies that manufacture colored panels, they come and go, making it a very unreliable industry. Petter has worked with colored solar panel projects several times and has worked in the solar cell industry with over 20 years of experience. Through the projects he has managed, he could tell that the around 10 colored solar panel projects that he and his team projected, were almost three times as expensive as if the project was to be achieved with standard panels. He highlights that there are costs not only from having different panels, but much around this. For example, when installing colored solar panels, all the clamps need to be the same color. To color these aluminum clamps is very expensive, and not reusable as the clamps for standard solar panels which can be used for many similar projects. With colored solar panel projects, the left-over materials cannot be reused by the installer, and then not be taken off the project bill, since no other project will have the exact same colors. This also shows that the business with colored solar panels is underdeveloped and needs time to become a commercially recognized and stable product. As Elin Elmhag explains it:

"*... it is new, it is very new, and it takes time for people to know that these products exist. After that, you need to convince architects and the architects do not keep track of solar panels. Then there needs to be a solar cell consultant who knows about the products, that can be in the early stages of the project and tell the architects [about colored solar panels]. Also, since it is a new product, people who buy them, property owners, need to have the courage to invest since it is hard to trust that it will work and there is a lot of uncertainty in it.*"

- Elin Elmhag

Petter Sjöström continues by saying that it would not help much if people knew about it. He says that even if people heard about colored solar panels and want a project proposal on it, they would not accept the offer when they found out the price. He thinks that the panels are too expensive compared to the mass-produced panels in, for example, China, where prices are much lower. So, it is not the awareness of the colored solar panels that is needed, it is the prices that need to come down. But even though there are uncertainties as both Petter and Elin mention, there is also potential. Architects are in the interviews mentioned several times as one of the main actors in colored solar panels. They are positive towards the colored panels since it gives them a larger freedom to implement solar solutions on different buildings. Making colored solar panels more known and available for architects would be an important step for the diffusion of the technology. Bernard Ranke emphasizes that the aesthetic appearance of colored solar panels is interrelated with the production of renewable energy. If an architect was to choose not to use solar panels on the facade of a large project, then this building would not produce any solar power and hence waste money on buying electricity from a coal power plant. In turn, as long as this building was to exist, emissions from the coal power plant would continue to pollute the world. So, as Bernard wants to highlight, the seemingly small choice of declining solar panels since they are unaesthetic, which is a normal occurrence in building projects, will cause so much detriment long-term. If instead, the architects had the choice to choose between different colors and then found a solar panel that fit the project, the focus would not have been that the colored panel had a few percent lower efficiency than the standard or being more expensive. The focus would be that the installation of the colored solar panels would create renewable electricity for the building, save money long-term, save the planet on years of emissions, as well as create a beautiful building that people could take inspiration from.

5.4 The diffusion of colored solar panels

Rickard Berg, who works as an energy and sustainability manager in Sigtuna municipality thinks a problem from municipalities is not showing their work more. He says that people have called him and asked why they have not installed solar panels, and he answers that they indeed have done that. People are curious and want to be invested in what is happening in their municipality, however, if they do not see and they are not noted, then it is hard for something to get the affirmation and recognition it might need for its development.

"*When we install solar panels, people approach us and ask us to look at their villa. A meeting such as this does not have to lead to a purchase immediately [...]. When you see that your neighbors are investing in solar panels, you yourself start thinking about it*"

- Bernard Ranke

"*I think people always get interested in new technology when they see a lot of public buildings. When you build a new property in the city or build a new one and it gets a lot of publicity, it is clear that it interests people more about solar cells.*"

- Paula Björk

A way of showing people progress, development, and innovation is by for example, installing screens on buildings that show how much power the solar panels have produced. Rickard says that they did this just because they wanted to make it more clear on the work the municipality is doing and in what way it benefits the community and environment.

Anders Elmqvist mentions in his interview that there is a lot of potential for colored solar panels on red roofs, a type of red roof tile that is very common in Sweden. He refers to a study that was done on the city of Malmö, where the potential for red solar panels was analyzed. A specific area in Malmö was discussed which had several buildings with only red roof tiles. The conclusion came to be that if the roofs were to be installed with red solar panels, 23.6 TWh would be produced annually, enough electricity to cover 10.000 apartments (Wendt Ursing, 2020). Anders works in Malmö and hence sees potential in red solar panels since he sees a lot of red roofs in Malmö. In the same way, other people see potential in different aspects. Group leader at Sweco in Halmstad, Nichlas Berg, says that there is not much potential for regular house owners, however, integrated colored solar panels as well as wanting the panels to blend in with the facade, has more potential according to him. So, the diffusion of colored solar panels will look different in different areas of the country, depending on what needs, problem areas and opportunities the city sees.

A hinder for the diffusion of colored solar panels has through the interviews been seen on the cost of the innovation. Lars Åbom, who is an installer of renewable energy and has experience within the field, continuously working towards the change from today's energy generation into renewable options, saw the cost as a hurdle. He says that he does not yet believe in the system of colored solar panels, because of the price being very expensive in comparison to standard solar panels. Though, he says this through the perspective he believes people think. Lars knows companies look for cheaper options and he sees this as a problematic, though, this is only because of the instability of the colored solar panel industry. As many of the interviewees mention, not much is known about the panels, what they do know is that it is expensive as of now. This brings forth further potential for the innovation since the electricity prices in Sweden have indications of becoming much higher within 10 to 20 years. For example, Swedish energy authorities have brought forward future scenarios where nuclear power production will have to be replaced by other renewable production sources. This is an assumption, however, with the Swedish goal of a fossil free country by 2045, it is highly plausible and an objective for Sweden. A removal or reduction of nuclear power would in turn cause the electricity prices to rise. This has already happened in countries such as Denmark and Germany, and since these neighboring countries affect Sweden, it could also affect the Swedish prices to rise. Hence, it would benefit solar energy because it would cause an incentive for solar panel installations to replace the higher electricity prices (Wargert et al., 2018).

"*It is always good with positive examples, to succeed in installing them on a building that is visible. It is costly and it is hard to do something about just that. But I am thinking that the more people who buy them, the more affordable it will get. If we get the production up, we can lower the costs. I am thinking a scenario in modern architecture, implementing colored solar panels in an area that is counted as popular, so when you look at it you get inspired.*"

- Ylva Jalming

The higher price on electricity is not the only reason that would cause colored solar panel prices to minimize. As Ylva Jalming, energy and climate advisor in Halmstad, describes, diffusion of the innovation, causing more production and sale of the panels would in an economical perspective bring about a lowering of prices.

Many of the solar panel experts emphasize that one large problematic with solar panels and their diffusion in general is that you cannot store the electricity you produce:

"*We overproduce a lot during the summer, however, a battery is too expensive to motivate a purchase. You cannot even store the electricity for more than 24 hours. You cannot store the electricity for a whole season which would be necessary. This becomes a challenge but can be seen as a benefit with solar panels. It pushes the development for cheaper storage solutions as well as pushes the development of better electricity networks so we can export the power and then eliminate coal and fossil power.*"

- Anders Elmqvist

Mats Danielsson thinks that the future for solar panels is the development of battery packs that will come with the installation of the panels. The prices for storage have been extremely high, however, he has seen cases of installations that show that the prices are on their way down. He thinks that a package such as this, with panels and reliable storage will attract many customers for the future. Paula Björk mentions another type of storage, namely electric car batteries as a storage. Instead of charging your car battery, her idea for the future is that the battery is charged by the extra energy from the solar panels. Then you will not need to charge the car battery from expensive peak electricity, rather it is charged directly to your car battery and used when needed. These thoughts are acknowledged by the international energy agency (International Energy Agency, 2020b), where it is tested in several countries, such as the Netherlands, Switzerland, and Japan. Here, electric vehicles are connected to a grid of solar panel electricity and can deliver energy to the consumers. Moreover, the main advantage of combining the solar panel energy system to storage is to create a larger self-consumption of the solar panel installation. Worldwide, storage is under development, and is incentivized to be developed by several countries, one of these being Sweden. The incentivization is through a government subsidy for private households. Though, what seems to be a key technology for specifically seasonal storage, which is one of the main wishes regarding solar panel storage, is green hydrogen production. This means creating a fuel from the PV energy, instead of fossil fuels (International Energy Agency, 2020a).

5.4.1 Subsidy

Sven-Ingvar highlights that the subsidy for solar panels in Sweden changes every year, making it hard to know what is right and what is wrong. It turns into a complicated process to install solar panels since there are too many rules and calculations to know. Ylva Jalming says that the government just changed the subsidy for installing solar panels to something called a green root deduction. Previously, a person had to apply for a subsidy when installing solar panels, but now the green root deduction is a sum of money directly deducted on the invoice received when the installation is complete (Skatteverket, 2021). Anders Elmqvist gives a comprehensive overview of how the subsidy has taken place over time, and what advantages and disadvantages it has led up to:

"*In the year 2017 we had many solar panels and we paid taxes on all of the solar electricity since we had a total of 255 kW. Later, these rules were changed so that the taxes paid were per facility over 255 kW. After this change we got motivated to install more [...]. We have understood that the regulations will change, costs will change. We have had it where you could get 70% in subsidies, that was a high pay off, but later it changed and became a lot lower.*"

- Anders Elmqvist

6 Analysis of the conducted interviews

In this chapter an analysis will be made based on the interviews. The analysis will follow the framework of content, context, and process. In comparison to the literature analysis, this chapter will not analyze areas from the interviews that relate to one of the specific categories from the framework. Since the interview answers are more in depth, subjective, and relating to both facts and the persons experience, the categories will be analyzed in a correlated manner. In the same way that the interviews were structured with subject specific categories, the framework in this chapter will be used in the same way, interrelated with the analysis. This chapter will then be followed by a discussion where the literature analysis and interview analysis are compared and discussed together.

6.1 Interviewees' different experiences

When analyzing the interviews, a distinctive feature could be seen in that the interviewees discussed the matter subjectively, based on their experience in their corporation and working city. The energy and climate advisors presented many thoughts on the importance of making the innovation of colored solar panels and solar panels in general, more affordable for the customer. Since they work with advising customers daily, they have a perspective on making innovations suitable for the everyday person. The interviewees working in a municipality provided insight on how the municipality works and the importance of marketing and diffusion in order to push the innovation forward. They emphasized that development would come when municipalities make it shown that the innovation is used, installed, and hence marketed to people. In comparison to this, the energy and climate advisors wanted to see a change in the storage for solar power, so that customers could save their electricity for peak hours and not have to buy electricity from other, non-renewable, sources. As many of the interviewees mention, solar panel installations have the option of also installing solar panel batteries for storage. Though, there was a consensus that this is not a good change for the solar panel industry, rather, the storage needs to be larger, able to hold more capacity and be affordable.

6.2 Next step for colored solar panel diffusion

When looking at the history of implementing standard solar panels, many of the interviewees say that support from the government with different types of subsidies, has helped the change of not using solar panels at all, to now being able to see them in every city. However, when asked about colored solar panels, the solar experts can be seen to switch focus for how the development will come to be. The focus is on architects and their major role in implementing colored solar panels. This could also be seen by the interview example of Vallastadens parking garage from 2017, the largest known colored solar panel project in Sweden. With this project, the municipality had set out the project of creating a facade that would show the municipality in a good light, and as a municipality that wants to develop for the better. The architects that got the project created the parking garage facade, resulting in the different colored solar panels, both lighting up the area and benefiting the building with renewable electricity, as well as the environment. As the interviewees hence mentioned, architects are currently the ones who are able to create a change in the colored solar panel market, by pushing the use of the panels for facades of a similar type to Vallastadens parking garage. The architects have an important role in the design stage and can be those who propose using colored solar panels, so, making this available to them can create a potential for future building projects. Through the interviews, it could be seen that a connection was drawn between the architect's knowledge on colored solar panels and the diffusion of the panels.

Furthermore, there were different perspectives on what needed to change first in order for there to be a diffusion of colored solar panels. Some of the interviewees said that the colored solar panels needed to be implemented and hence become commercially marketed. This could be through, for example, the push from architects in larger municipal projects. Other interviewees said that the colored solar panels first needed to be lowered in price, and increase in efficiency, before being implemented more. They found that the panels could not stand a chance against the standard solar panels and could hence not be marketed or diffused since no one would want to invest. The different thoughts on how the change needs to occur could be contradicting since it is hard to create a market and develop something that is not first being talked about, installed, tested, and spread.

6.3 Colored solar panels for private individuals

A consensus could in a way be seen in the fact that the different colors would not be used for aesthetic reasons, for private individuals. As some of the interviewees mention, the different colors are pretty on large buildings that want to spread a message or create a building that attracts attention. The various amounts of colors could be used to create a beautiful building that markets solar energy and makes the building a topic of discussion. This both markets the solar panel technology, while marketing the building and the corporation who chose to install it, saying that they are a renewable company. Private individuals do not want to market themselves in the same way, rather, they would choose the colored solar panels in order it them to melt in with the colors of the house. As the interviewees described it, hiding the panels. An example of this is when in one of the interviews discussing Malmö city having an area with only houses with red tile roofs. As Anders Elmqvist describes it, the potential for red solar panels in this type of area is enormous, showing the potential of colored solar panels in a way of discretely having them without showing. It appears that the colored solar panels are too expensive for private individuals since they do not bring other benefits that the standard solar panels could not. As seen in the interviews, people are often concerned and hesitant to install standard solar panels because of the price, including the long payback time and additional costs. When then adding the factor of the colored layer, making the modules even more expensive, and then having to adapt the module mounts to match the color of the panel, it adds even more expenses. Therefore architects and larger projects were mentioned in combination to colored solar panels, since larger municipal projects have a bigger budget.

6.4 Costs

Some of the solar experts did not see costs as a problem when discussing to add colored solar panels in projects. They mention that not only can the energy budget be used for it, however, the marketing budget can also be made use of. This is because it creates a good image for the city, showing that they are working towards the national goal that Sweden has of becoming a country that only uses renewable energy. For example, Halmstad municipality has won an award for their investments on solar panels and becoming an inspiration for other cities. As mentioned in the interviewees, many large installations such as those that Halmstad has done, are expensive. However, they create value in several different ways, then balancing out what was initially expensive. The solar panels create solar energy, which is a renewable resource, it leaves a smaller footprint on the environment compared to the energy that would be needed with coal power plants. Installing solar panels also creates profit by producing electricity that can cover a part or the whole power demand of the building, depending on how large the installation is. But also, by investing in solar panels similarly to Halmstad municipality, it creates value by creating awareness and contributing to a sustainable society. Hence, the cost is not always about the actual cost of the materials or the installation, meaning you look only at the payback time and price of the installation when wanting to invest. Instead, large projects and cities can gain value in many other ways when investing in colored solar panels, including profiting economically.

However, when looking at storage for solar panels, this is, through the interviews, seen as a hurdle that makes the solar panel image even more expensive. The solar experts say that not only is storage very expensive, but it is also very underdeveloped. There is a need for long-term or seasonal storage in order to benefit on the solar panels as much as possible. Much of the electricity that is not used is sold back to an electricity company. When it later becomes winter and there is not much sun, the sold electricity would have come in handy if there would have been a place to store it over the darker seasons. It creates an additional cost factor which could potentially slow the potential of colored solar panels down, since colored solar panels are already more expensive than the standard ones. This, in combination with the expensive storage, makes it nearly impossible for the regular house owner to invest in these.

6.5 Marketing colored solar panels

When conducting the interviews, people were specifically chosen because of their knowledge and experience, in different senses, with solar panels. However, even with this, many of the solar experts had not heard or did now know much at all about colored solar panels. This not only shows that people who do not know much about solar panels in general, probably do not know that colored solar panels even exist. It also shows that colored solar panels are not being advertised at all, which some of the interviewees highlight, saying that if there is going to be a market for colored solar panels, they first need to be marketed. In Sweden, there are commercials for solar panels, on television, on social media, in newspapers, and even on the radio, however, this is not the case with colored solar panels. The interviews point out that, both by directly saying that the panels need to be advertised, but also indirectly by the interviewees' lack of knowledge on the modules, that colored solar panels need to be seen and heard about more.

A problematic with the marketing of colored solar panels could be the instability of colored solar panel companies. In one of the interviews, it is said that many colored solar panel companies have come and gone, becoming an unreliable and short-term scheme. Since the market for colored solar panels have not become big, companies might have started and tried to sell these, but failed, and hence having to close down. It is then hard for the innovation to even be advertised since no one is willing to buy them, instead having to close down and starting all over in a new company. It is this beginning that is hard, creating a trustworthy product that people are willing to risk investing in, and when created, advertise it in a way that can be seen as reliable and beneficial to the customer.

7 Discussion

The interviews were conducted with different actors in the business. They had different experiences and worked within different companies, which could be seen through their answers. While some had a customer perspective, others had a marketing perspective, as well as environment perspective. For example, it could be seen that the energy and climate advisors, although in different cities, expressed themselves in similar ways. They started many of their answers in the same way, but as the interviews went on, more of their own thoughts could be seen coming through. This is most likely due to having the same working position but in different cities, and in a way being a part of this union. This was also a good way to see what they lecture about when talking to customers or property owners when they call in and want to know about solar panels. It shows how common the colored solar panels are and if it even is an aspect that they can bring up, which it seemed not to be. One of the energy and climate advisors had her focus in the interview on lowering the energy costs and storing energy, and when mentioning colored solar panels, she said that they could create a positive view on solar panels for people who see them. Here, the perspective is focused on the people, what people will benefit from and what people will think. She herself pointed out that she has not worked with colored solar panels since she is an advisor for villas, and that the colored panels are more for bigger buildings. In a way, this is true, since all the projects discussed in the literature, that have installed colored solar panels, are large buildings such as the Copenhagen international school, and parking garage in Linköping.

The interview analysis showed great drawbacks in terms of the instability of colored solar panel companies, and the marketing of this technology since many of the solar panel experts had not heard much of it. In connection to the literature analysis, we can see that information on colored solar panels is limited. Though, what is positive is that there are successful projects that can be used as a reference when talking about colored solar panels. Sweden, Denmark, Switzerland, and others have shown how solar panels on a large building can be beautiful when colored. This same remarkableness would not be achieved if the projects used standard solar panels, showing that the color aspects add great value. However, an aspect that can be questioned is the fact that the city of Halmstad has a large history of extraordinary development within the solar panel industry, but they do not have a project that has used colored solar panels. This can also be another proof for the fact thar colored solar panels have not had their breakthrough yet, meaning there is potential for the near future for the solar panel industry to expand in Sweden.

In both the literature and interview analysis, we can see that one of the mainly discussed topics regarding colored solar panels, is that they are very multi-usable. When first starting this thesis, the preconception was that colored solar panels would only have a potential for large municipal buildings because people do not want multiple colors on their house. Though, through analyzing the literature and interviews, it could be seen that colored solar panels have the quality of being bold, colored and seen, on large buildings, or hidden and useful on villas and houses that in other cases are not allowed building permits or cannot be changed in color. This multi-purpose factor of the colored solar panels makes the panel just as important to develop as the standard panel. Colored solar panels are less efficient than standard panels, however, they might have more value even despite this, because of them being useful in many different projects, being aesthetically pleasing, and sending a message for the future renewable society.

My findings in the two analyses also suggest that Sweden’s subsidies for solar panels are helpful since there is a stigma that installing solar panels is expensive. Though, the subsidies are shown to be in constant change. Every year there are new rules regarding how much subsidy will be offered and available, meaning this is new information that people need to find. If they one year installed solar panels and want to recommend this to their neighbors three years later, the rules for subsidy would have changed. As stated in the analysis of the theoretical frame of reference, subsidy and peer effect is of very high importance regarding the diffusion of solar panels in Sweden, meaning it is similarly affecting the colored PV market. Enough information and knowledge is needed for people and for/from municipalities, as well as and from higher third parties, in order for customers to trust and want to accept the innovation of colored solar panels. The most important thing is that the subsidy for solar panels continues to exist in order to push people to install without being hindered by the preconception of being too expensive.

8 Conclusion

This research aimed to identify the benefits and potential, in different senses, of colored solar panels for a renewable society. Based on a qualitative analysis of the commonly used standard solar panels compared to the innovation of colored solar panels, it can be concluded that the the efficiency is slightly lower in the colored solar panel technology. Besides this, the interrelation between colored and uncolored solar panels has been concluded as an important factor to consider. The colored solar panels are built on a standard panel, however, with an extra colored layer. It also seems as if the uncolored solar panels will always have this static advantage of having a higher efficiency. The standard panel is cheaper, meaning that the colored solar panel technology must become more affordable in order to get to the same diffusion level of the standard solar panels. The results hence shows that the diffusion of the colored solar panel is interplayed with the content and context of the uncolored solar panel technology. It could be seen that the colored solar panel technology is not its own solar module technology, rather, it is a color layer that allows transmittance with various transparencies. In order for the electricity production for the two panel technologies to reach the same efficiency, the colored layer needs to be created in a way that does not minimize the transmittance, which in the results shows an unlikely possibility. Though, while the transmittance is minimized by the colored layer in solar panels, this provides new potential for the standard solar module to develop from the general 20% efficiency as of today. Further research is hence needed to determine how this could be developed, benefiting both the standard and colored solar panel modules.

This research clearly illustrates the benefits of installing solar panels on municipality buildings in Sweden. Not only is it a push in the right direction for the renewable society, but it can be concluded that it would help make the buildings self-providing of clean electricity, with the added value of social positivity with colored panels. People become more aware of the solar panels when they can be seen in an architecturally pleasing perspective. It creates awareness, and the building itself becomes an inspiration for other buildings and municipalities. It also brings the value of creating a market for the colored panels, which can be used by private individuals that cannot get a building permit or do not want to destroy the aesthetic of their house with a blue or black solar panel. Also, in a long-term perspective, the continuous development of solar panels and colored solar panels, would push for the research and development of batteries and storage which in terms can add large value in the solar panel market.

This research also aimed to gain an understanding on the diffusion of colored and uncolored solar panels, and what benefits this would bring in Sweden. The interviews provided a lot of answers to this, and it could be concluded that marketing is one of the main factors for the diffusion. Not only would marketing of colored solar panels show people that they are useful, but it would also make it an option for architects to use in the design stage of a building project. Solar panels are not commonly integrated on buildings since they can easily ruin the building aesthetic, so architects choose not to use them. However, colored solar panels would allow for this option to become more attractive, and hence open the market for both uncolored and colored panels because of these being interrelated. It also shows that the different content and contexts for the technologies explains the diffusion processes of both the colored and uncolored solar panels. For colored solar panels, the aesthetically pleasing content aspect enabled the technology to gain a place in the market overall. Furthermore, the change in context regarding the small place in the market that standard solar panels have, enabled a push for developing and marketing the colored PV technology. While this research clearly shows that there is major potential for colored solar panels and their diffusion, it also raises the question of the stability of the industry. As seen in the results, the colored solar panel companies are not many, and are relatively new. To better understand the implications of this, future studies would need to address the stability and reliability of the colored solar panel companies available to see if the potential for a long-term market is there.

Although there are many limitations on the research available on colored solar panels, this thesis provides an overview on the innovation of colored solar panels, the major companies for these, and how they differ from standard modules. The presented interviews from the solar cell experts also provided different perspectives on the topic, as well as showed the positive attitude towards the innovation, and the several reasons on how colored solar panels could bring benefits for people, the society and country. This thesis can be used as a base to show the potential of colored solar panels, and as a contribution to the limited research on the subject. Concretely, the colored solar panels could be adding value for the diffusion of the solar panel market as a whole. And for this to happen, the topic of colored solar panels needs to be heard, and this thesis is a way of making it heard.

9 References

Ahrberg, P., 2021. *Solceller i Sverige: Statistik & prognos 2021 | SolcellsOfferter*. [online] SolcellsOfferter | Få prisförslag på installation eller solcellspaket. Available at: <https://www.solcellsofferter.se/solceller-sverige/> [Accessed 19 February 2021].

Amberscript, 2021. *Intervju transkription*. [online] Available at: https://www.amberscript.com/sv/intervju-transkription/ [Accessed 1 June 2021].

Bozkurt, B., 2019. *Solar Cell and Solar Panel Production*. [online] Available at: <https://www.researchgate.net/publication/333603927_SOLAR_CELL_AND_SOLAR_PANEL_PRODUCTION> [Accessed 4 April 2021].

Bülow, E., 2021a. *Solcellsbidrag 2021 → Bidrag till solceller 【Grönt Avdrag】*. [online] HemSol. Available at: <https://hemsol.se/vanliga-fragor/solcellsbidrag/> [Accessed 23 March 2021].

Bülow, E., 2021b. *Hur mycket solceller behöver man? - Uppdaterat 2021 | HemSol*. [online] HemSol. Available at: <https://hemsol.se/vanliga-fragor/hur-mycket-solceller-behover-man/> [Accessed 3 April 2021].

Dahlgren, S., Kanda, W. & Anderberg, S. 2019. Drivers for and barriers to biogas use in manufacturing, road transport and shipping: a demand-side perspective. [online] Available at: <https://doi.org/10.1080/17597269.2019.1657661> [Accessed 2 March 2021].

Energimyndigheten, 2019. *Bygglov och byggregler*. [online] Available at: <https://www.energimyndigheten.se/fornybart/solelportalen/vilka-rattigheter-och-skyldigheter-har-jag-vid-installation/kraver-installationen-bygglov/> [Accessed 11 February 2021].

Energimyndigheten, 2020. *Solcellsstatistik 2019 – nu finns 44 000 solcellsanläggningar i Sverige*. [online] Available at: <http://www.energimyndigheten.se/nyhetsarkiv/2020/solcellsstatistik-2019--nu-finns-44-000-solcellsanlaggningar-i-sverige/> [Accessed 19 February 2021].

Eonenergy, 2021. *Solar panels installation*. [online] Available at: <https://www.eonenergy.com/solar-panels/installation.html> [Accessed 1 April 2021].

Gallagher, S., 2013. *Why & How Governments Support Renewable Energy*. [online] Available at https://www.jstor.org/stable/43297301> [Accessed 26 June 2021].

Gul, M., Kotak, Y. and Muneer, T., 2016. *Review on recent trend of solar photovoltaic technology*. [online] Available at: <https://doi.org/10.1177/0144598716650552> [Accessed 6 March 2021].

Han, A., 2014. *Efficiency Of Solar Pv, Then, Now And Future*. Lafayette, [online] Available at: https://sites.lafayette.edu/egrs352-sp14-pv/technology/history-of-pv-technology/> [Accessed 26 June 2021]

HemSol. 2021. *Vad kostar solceller? Allt om pris på solpaneler 2021 | HemSol*. [online] Available at: <https://hemsol.se/pris-pa-solceller/> [Accessed 25 March 2021].

International Energy Agency, 2020a. *TRENDS IN PHOTOVOLTAIC APPLICATIONS*. [online] Available at: <https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf> [Accessed 15 April 2021].

International Energy Agency, 2020b. *Snapshot of Global PV Markets*. [online] Available at: <https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf> [Accessed 14 April 2021].

International Energy Agency, 2019. *National Survey Report of PV Power Applications in Sweden*. [online] Available at: <https://iea-pvps.org/wp-content/uploads/2020/08/National-Survey-Report-of-PV-Power-Applications-in-Sweden-2019.pdf> [Accessed 7 April 2021].

Kameleon Solar. 2021. *About ColorBlast® - Kameleon Solar*. [online] Available at: <https://kameleonsolar.com/about-colorblast/> [Accessed 8 March 2021].

Kesselfors, S., 2017. Vallastaden i Linköping får parkeringshus med solceller. *Solenerginyheter*, [online] Available at: <https://www.solenerginyheter.se/20190803/67/vallastaden-i-linkoping-far-parkeringshus-med-solceller> [Accessed 26 March 2021].

Kinoshita, A., Yoshioka, S., and Miyazaki, J. 2008. *Physics of structural colors*. [online] Available at: <http://stacks.iop.org/RoPP/71/076401> [Accessed 15 March 2021].

Matasci, S., 2021. *How solar panel cost and efficiency have changed over time*. Energysage, [online] Available at: https://news.energysage.com/solar-panel-efficiency-cost-over-time/> [Accessed 26 June 2021].

Mathiesen, B., Lund, H., Connolly, D., Wenzel, H., Ostergaard, P., Möller, B., et al. 2015. *Smart Energy Systems for coherent 100% renewable energyand transport solutions*. [online] p.x. Available at: <https://doi.org/10.1016/j.apenergy.2015.01.075> [Accessed 10 March 2021].

Mehleri, E., Zervas, P., Sarimveis, H., Palyvos, J. and Markatos, N., 2010. *Determination of the optimal tilt angle and orientation for solarphotovoltaic arrays*. p.x.

Mundaca, L., & Samahita, M., 2020. *What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden.* Energy Research & Social Science (60) [online] Available at: https://doi.org/10.1016/j.erss.2019.101319 [Accessed 1 august 2021].

Naturskyddsföreningen. 2021. *Vanliga frågor vi får om solceller*. [online] Available at: <https://www.naturskyddsforeningen.se/faqsol> [Accessed 1 April 2021].

Neuman, W. L. (2014). *Social research methods: qualitative and quantitative approaches*. Boston, Pearson/AandB.

Offerman, C., 2012. *Sätter focus på solenergi*. Miljö & utveckling. Available at: https://miljo-utveckling.se/satter-fokus-pa-solenergi/> [Accessed 26 June 2021].

Palm, A., 2016. *Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market.* Energy Research & Social Science (14), pp. 1-12 [online] Available at: https://doi.org/10.1016/j.erss.2015.12.027 [Accessed 1 August 2021].

Palm, J., & Eriksson, E., 2018. *Residential solar electricity adoption: how households in Sweden search for and use information.* Sustainability and Society 8:14. [online]. Available at: https://doi.org/10.1186/s13705-018-0156-1 [Accessed 1 August 2021].

Pelle, M., Lucchi, E., Maturi, L., Astigarraga, A. and Causone, F., 2020. *Coloured BIPV Technologies: Methodological and Experimental Assessment for Architecturally Sensitive Areas*. [online] Available at: <https://doi.org/10.3390/en13174506> [Accessed 2 April 2021].

Pettigrew, A. M. and Whipp, R. (1991) *Managing Change for Competitive Success.* Oxford: Basil Blackwell.

Solens Energi. *Solpaneler - så fungerar det! Lär dig mer om tekniken bakom solel*. [online] Available at: <https://solensenergi.se/tekniken-bakom-solpaneler/> [Accessed 25 February 2021].

SMHI. 2021. *Solstrålning i Sverige | SMHI*. [online] Available at: <https://www.smhi.se/kunskapsbanken/meteorologi/solstralning-i-sverige-1.89984> [Accessed 4 April 2021].

Stadsmuseet. 2021. *Frågor och svar om klassificering - Stadsmuseet*. [online] Available at: <https://stadsmuseet.stockholm.se/om-hus2/klassificering-och-k-markning/fragor-och-svar-om-klassificering/> [Accessed 15 April 2021].

Strong, S., 2016. *Building Integrated Photovoltaics (BIPV)*. [online] Available at: <https://www.wbdg.org/resources/building-integrated-photovoltaics-bipv> [Accessed 12 March 2021].

SwissINSO. *SwissINSO — Technology*. [online] Available at: <https://www.swissinso.com/technology> [Accessed 3 February 2021].

Tunahan, I., 2015. *Solar cells Review*. [online] İstanbul. Available at: <https://www.researchgate.net/publication/276423464_Solar_Cells_review> [Accessed 13 March 2021].

Vattenfall. 2019. Solrapporten – fakta och myter om solenergi. [online]. Available at: <https://www.vattenfall.se/4ac2ca/globalassets/content-hub/hus--hem/solfaktorn/solrapporten-2019.pdf> [Accessed 10 February 2021].

Wallner, E., 2019. *Hur effektiva är solceller 2019, och hur ser det ut om tio år? - Solcellskollen*. [online] Solcellskollen.se. Available at: <https://www.solcellskollen.se/blogg/hur-effektiva-ar-solceller-2019-och-hur-ser-det-ut-om-tio-ar> [Accessed 5 February 2021].

Safaa Aqel

HALMSTAD UNIVERSITY

PO Box 823, SE-301 18 Halmstad
Phone: +35 46 16 71 00
E-mail: registrator@hh.se
www.hh.se