Solar Energy: from Photons to Future Societal Impact

Strategic Assessment of Solar PV Implementation, Case Study.

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Abstract

To fight climate change and to strengthen the strategic sovereignty of the European energy supply, the deployment of renewables must accelerate. PV electricity is now one of the key components in the electricity mix and will contribute to more electricity production in the future. Such transformation in energy system and infrastructure can be a path of opportunity by enabling economic growth, creating jobs and reducing environmental damages and human healthcare costs by lowering pollutions. However, due to intermittency and variability of renewable energy sources, there are concerns regarding flexibility management, storage, land use and resource intensity, scarce metals, energy security, transmission reliability, market reform and fair transition for different actors and communities. Moreover, energy policies should be aligned with climate objectives and strengthening local capacities. Thus, for strategic assessment of such transformative energy plans, countries have to conduct comprehensive discussion about the kind of future societies in which energy will interact and engage in analytical assessment of environmental, societal and economic impacts to align the society with upcoming transformation. This project conveys a strategic assessment of solar PV implementation plans in Gothenburg in the context of Swedish energy plans and scenarios by 2035 and illustrates the enablers and restrictions for the set targets.

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1.Introduction

The share of electricity in total energy use must increase to almost 50% by 2050, up from 20% today. Renewables would then make up two-thirds of energy consumption and 86% of power generation. Renewable electricity paired with deep electrification could reduce CO2 emissions by 60%, representing the largest share of the reductions necessary in the energy sector (IRENA, 2019). Among renewable energies, photovoltaic solar energy has a prominent place with a 25% increase in installed capacity worldwide in 2018, including the development of grid-connected photovoltaic solar power plants (Brunet et al., 2021). Global electricity markets are constantly evolving to meet the growing demand for renewables by different types of consumers. One important aspect of energy system transformation by renewables, and particularly the case of solar, is rapid decline of their costs. Overall, the fall in electricity costs from utility scale solar photovoltaic (PV) projects since 2010 has been remarkable, with the global average cost declining 73% (IRENA, 2018).

Sweden has achieved an electricity production system with a minimum carbon dioxide emission, figure 1 illustrates the current energy mix (energimyndigheten, 2021). The strategic goal according to the Swedish Energi Agency is to achieve 100% renewable electricity production by 2040. Such a strategic direction implies that Solar generation needs to go from 0.6% to 8.3%, the modelled electricity generation mix in 2040 is presented in figure 2 (Fogelström, 2021).

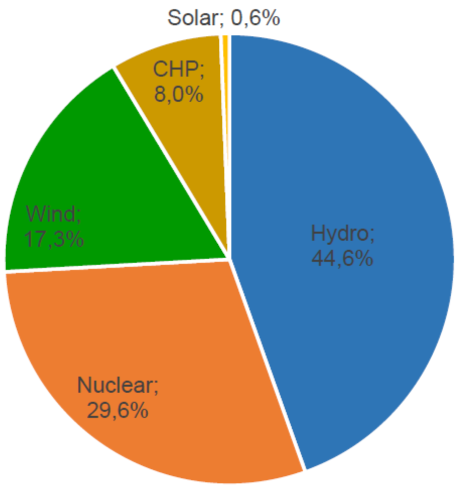

Figure 1 Electricity production in Sweden 2020

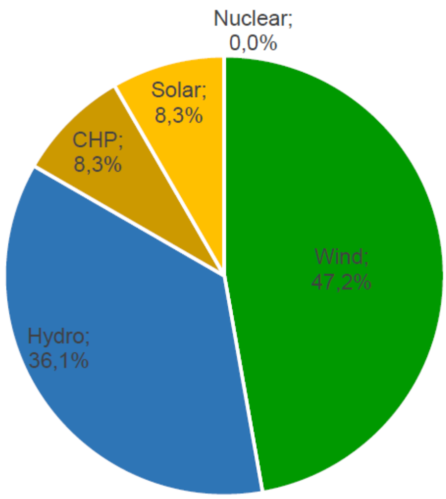

Figure 2 Figure 1 Electricity production in Sweden 2040

Such transformation in energy system and infrastructure can be a path of opportunity by enabling economic growth, creating jobs and reducing environmental damages and human healthcare costs by lowering pollutions. However, resource intensity, scarce metals, energy security and fair transition for different regions and communities as well as addressing uncertainties are only a few topics among many more concerns which matter for a sustainable development. To achieve needs to be matched by such transformative actions in the renewable energy age, working in partnership with the multilateral system, institutional and financial as well as engaging with the private sector is key. Moreover, energy policies should be aligned with climate objectives and strengthening local capacities. Thus, for assessing sustainability of such transformative energy plans, countries have to conduct comprehensive discussion about the kind of future societies in which energy will interact and engage in analytical and strategic assessment of environmental, societal and economic impacts to foresee the consequences of such plans. This project aims to convey a strategic assessment of solar PV implementation plans in Gothenburg in the context of Swedish energy plans and scenarios by 2035.

2.Aim and objective

The aim of this project is to predict the potential level of penetration of solar PV in Gothenburg by 2035 and to evaluate the factors which lead to different scenarios and consequences. Moreover, it is aimed to investigate perspectives regarding policies, socio-technical feasibilities, market readiness and resources associated with solar PV implementation.

3.Method

Assessing the sustainability and strategic deployment of solar PV in Gothenburg requires having a better understanding of the socio-technical and market aspects of energy system in Sweden. Therefore, an explorative approach towards the future is considered both quantitatively and qualitatively. Firstly, The Swedish Energy Agency (2016) has already developed explorative scenarios of energy futures in Sweden, "Four Futures", which are considered as baseline of our calculative analysis. These baselines provide a basis as reference for a modern energy dialogue by adopting a holistic approach and a societal perspective supported by the population, politicians, and the wider world (mega trends) to set courses for the year 2035 while looking ahead to the year 2050. Different scenarios are described briefly in Table 1.

Baseline	Assumptions	Main Priority & State's focus	Energy system	Energy use (TWH) & Share of renewable	Demand-side flexibility
1	It is important that society ensures that energy prices are low, especially for industry. Welfare is based on economic growth and the availability of jobs in traditional industry. Secure access to energy is also one of the main priorities.	Energy works as a fuel for growth and well-being. Need of the industrial and commercial sector.	Centralized	375 TWH 50%	Limited
2	It involves reducing the energy system's environmental impact and Helping to resolve a global issue. Important factors here are ecological sustainability and global justice, which	Energy is a globally limited resource to be justly shared. Fast climate adjustment.	Renewable	243 TWH 100%	Medium to high

	characterise its solutions.				
3	It is very much based on people's own initiatives and consumers who want to have individual solutions and flexibility. Here, green energy is a strong driving force. Decentralisation, small-scale private production and purchasing services are important elements.	Energy is a means to express individuals' lifestyle. Individual solutions.	Decentralized	323 TWH 75%	High in the own system
4	It has a strong climate focus. Sweden has chosen to become a forerunner in green growth and develops the export market for environmental technology and bio industry. This entails an investment in new types of jobs.	Energy is a trampoline for growth on terms dictated by the climate. Research and innovation.	High-tech	326 TWH 100%	High and entirely automated

Table 1 Four Scenarios (Swedish Energy Agency, 2016).

Based on the priorities and assumptions in each path, there are different allocated share of energy sources to supply the projected energy system's targets. Solar Power reliance also varies depending on what energy system, societal perspective and other sets of assumptions including spatial planning, lifestyle and housing, industry, transport, new electricity markets and policy instruments are set.

Electricity system in 2035 and final energy use including distribution losses are displayed for colour coded baselines in Figure 3. Therefore, these baselines were complemented with generation assumptions based on an analysis of the current/ past solar energy contribution to the country's energy mix. Furthermore, the model is coupled with qualitative assessment tools reflecting the ecological impacts of the emerging solar PV in Gothenburg energy mix.

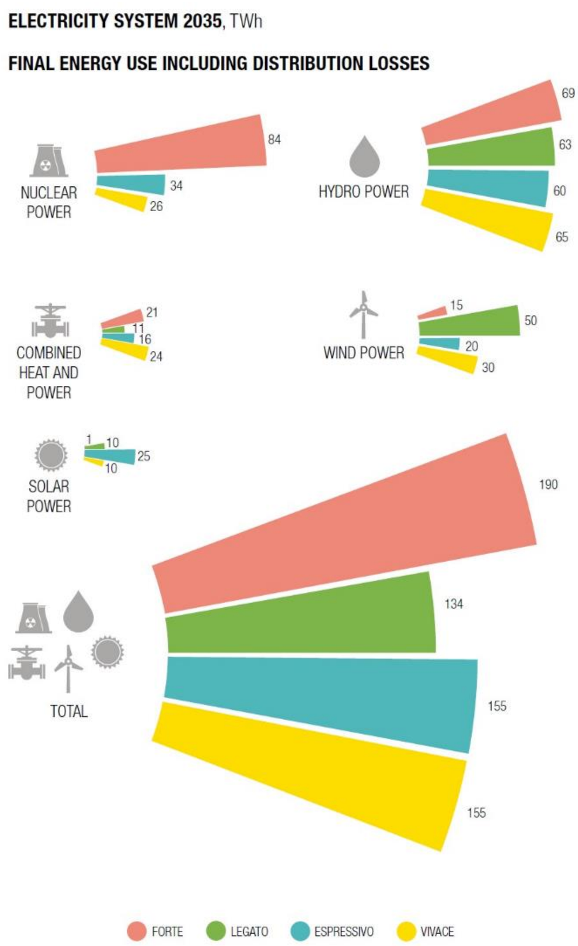

Figure 3 Electricity system, 2035, TWH (Swedish Energy Agency, 2016).

The model analysed both historical and expected growth of solar in PV, a trendline was then utilized to quantify the annual increase of solar PV capacity in Gothenburg. The model takes into consideration the historical deployment of grid- connected solar PV in Sweden. An energy analysis was conducted, it has been estimated that between 2016-2021, the market area (SE3) was always contributing with 66% to the Solar power generation in Sweden. Gothenburg production was assessed based on the available production data, and the future scenarios were built with the assumption that each.

Year	Sweden Solar Production (Gwh)	SE3 Solar Production (Gwh)	SE3 Ratio of Swedish Solar Production
2016	50.88	32.83	65%
2017	79.15	52.26	66%
2018	147.59	97.80	66%
2019	256.46	169.22	66%
2020	457.68	301.39	66%
2021	637.74	420.54	66%

Table 2 Solar Production in Sweden

In addition to the baseline, the model investigated the possibility of wide diffusion of solar PV modules used for self-sufficiency, by individuals and small businesses, without trading with the grid (SSPV). This calculation was based on the estimated capacity of on-grid solar connection and the underlying assumptions of each scenario. The following table illustrates the suggested ranges proposed by the four scenarios. An enabling and a crucial factor to the development of SSPV modules is the policy instrument in place, in current Swedish Scheme solar PV module under 255 KW are exempted from paying tax on use of self- produced electricity, further policies encouraging the local production of Solar for self-production would be expected if the strategic direction is to decentralize the electricity generation and increase the prosumers in the system.

Scenario	SSPV solar as % of on-grid capacity	Scenario basis
First Scenario	50% to 40%	Government Investments in Nuclear power. Hydropower being renewed.
Second Scenario	50% to 60%	Government issues certificate system, which favours utility scale mature technologies
Third Scenario	50% to 75%	More investment in local level with more focus on individual solutions and self-sufficiency
Fourth Scenario	50% to 80%	Government investing heavily in renewable electricity production

Table 3 Hypothesis for SSPV penetration

After calculations were done, stakeholders from academia and industry were interviewed to gather data regarding their perspectives and thoughts about solar PV implementation. Interviewee's list can be seen in the table 4. All interviews took place in January and February 2022 and the initials are used in the discussion part to refer to each person's perspectives.

Name	Initials	Company or institution	Title
Marika Edoff	ME	Department of Material Science and Engineering, Uppsala University	Professor in Solid State Electronics, spec. Solar Cells Division head, Solar Cell Technology
Johan Lindahl	JL	Becquerel Sweden and European Solar Manufacturing Council	Secretary General at European Solar Manufacturing Council and Founder of Becquerel Sweden
Kristina Hojckova	KH	Horizon Power	Senior Strategy Analyst
Yibo Zhao	YZ	Powercell	Business Manager Asia
Rebecca Palmgren	RP	Göteborg Energi	Product manager
Håkan Spångberg	HS	Klimat Invest	Board Member
Lars Hedström	LH	Solkompaniet	Founder and vice President

Table 4 Interviewees List

4.Results

The modelling work is resulted in 4 different future possibilities when it comes to the installed capacity of solar PV in Gothenburg, the first scenario has already been exceeded as of today in 2022, such a huge penetration for the past years indicates a significant change in the socio-technology landscape enabling such a fast-expansion of solar PV and the unexpected drop in technologies' prices.

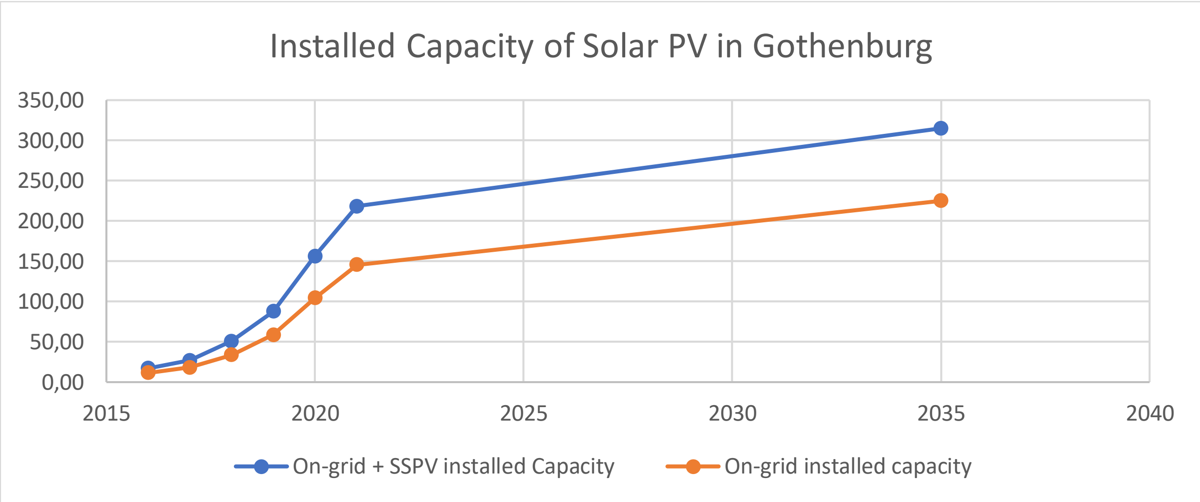

Figure 4 First Scenario Installed Solar PV capacity in Gothenburg (MW)

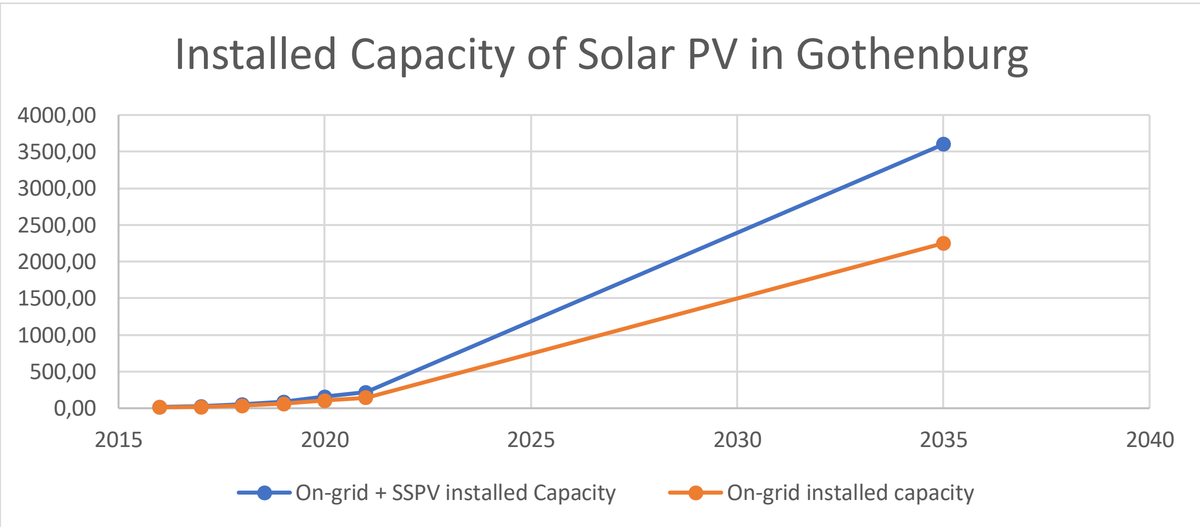

Figure 5 Second Scenario Installed Solar PV capacity in Gothenburg (MW)

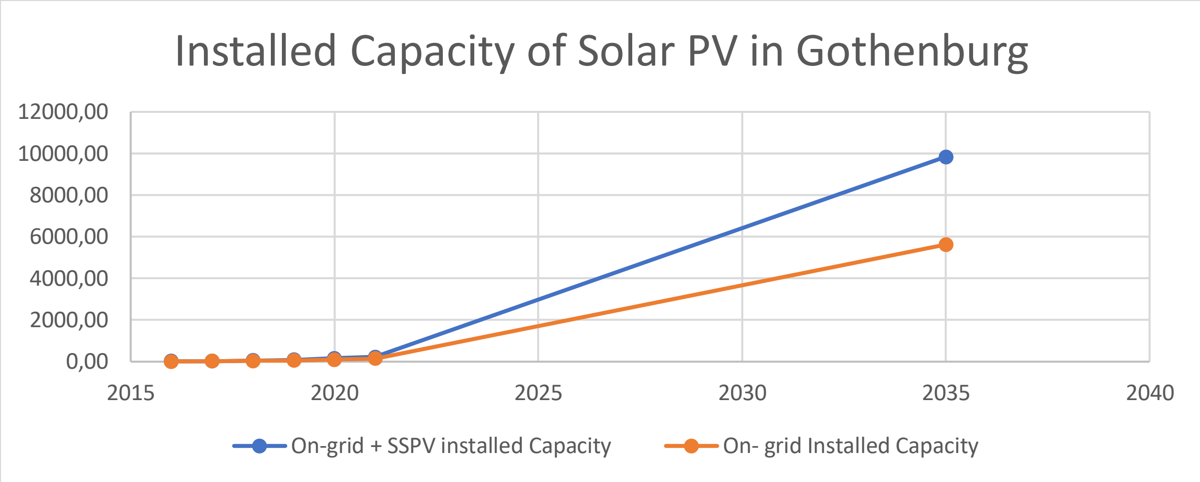

Figure 6 Third Scenario Installed Solar PV capacity in Gothenburg (MW)

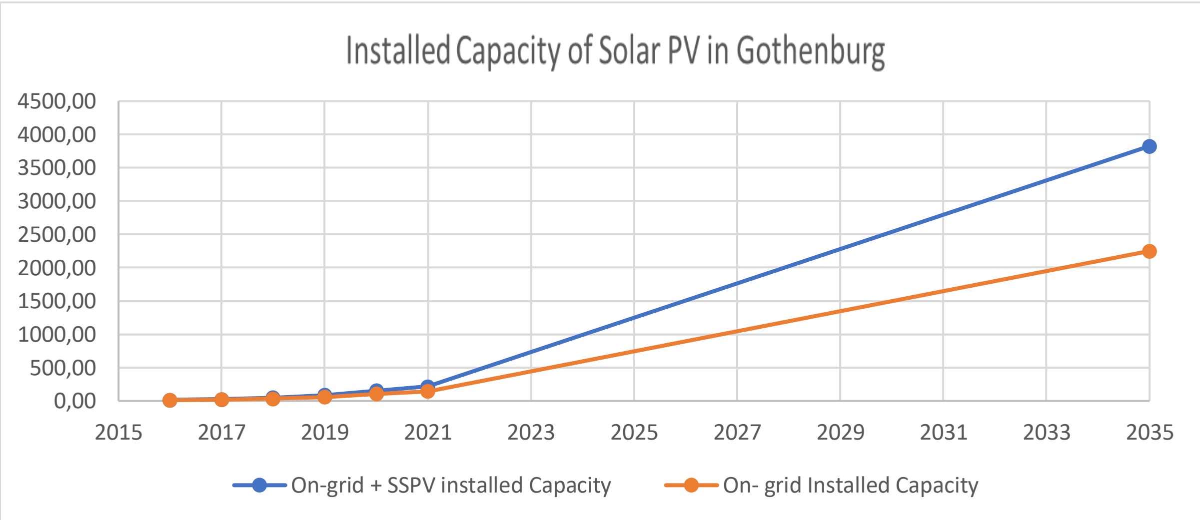

Figure 7 Fourth Scenario Installed Solar PV capacity in Gothenburg (MW)

The following table illustrates the required area to install the solar PV in different modules, the calculations consider the on-grid capacity in each scenario and compare the land availability with the available land in Gothenburg (447.5 sq. Km) and in Vastra Gotland county (25,274 sq. Km). these numbers could be seen in reference to the direct land use by wind power. Industrial references estimates that power intensity for solar is roughly 10 times of wind, while other estimates suggests that solar has an average of 5.7 W/m^2 while wind power has 0.9 W/m^2(Saunders, 2013). One important aspect that should be noted here, is that the given land use impact doesn't take into consideration in-direct land use: i.e., mining, cells manufacturing and flexibility measurements which are likely to be in place when the share of solar production increases.

Scenario	Solar PV area (Sq. Km)	In reference to Gothenburg	In reference to Vastra-Gotland
First	2.6	0.6%	0.01%
Second	25.7	6%	0.1%
Third	64.3	14%	0.3%
Fourth	25.7	6%	0.1%

Table 5 Land Use in different solar PV scenarios

5.Discussion

In order to assess the potential future scenarios of solar PV integration in Gothenburg energy system, this project investigated the mechanisms behind such process to unravel the driving and limiting factors via testing existing scenarios and getting feedbacks from interviews. The following questions discuss different aspects to help draw a picture regarding the relative discourses. Initials are used to refer to interviewees which are listed in Table 4.

1-How does the future energy system development is predicted regarding solar PV penetration?

Future energy system is highly dependent on many factors such as emerging technologies and their costs, socio-technical aspects of fusion of new technologies, available infrastructure, and the interplay between different sectors like transportation, different industries, and energy system. Moreover, supply chain, regulations and the availability of materials needed for development of new technologies like solar cells or batteries are of a crucial importance. Thus, political, social, environmental, and economic factors matter when it comes to the prospects of energy system. It is predictable though that, the future energy system will certainly consist of more sustainable sources like solar, hydropower, wind etc. Yet, the degree to which solar PV fusion will occur has been investigated in this report via attained perspectives from different interviews and reflections on future energy scenarios and analysis and calculations on that basis.

Hence, it is concluded that a share of 10-20% of solar energy in Sweden's energy system is quite predictable. 10% is expected given the incremental growth rate on the same conditions as today. However, a higher share to the limit of 20% in 10 to 15 years will occur only if more transformational landscape shifts occur to give way to new set of conditions, market values and actors in play. This has been particularly emphasized when interviewing ME and JL. Challenges like cannibalization effect due to decreasing electricity prices in existing market structure, variability and storage issues, frequency and voltage regulation also matter and act as limiting factors for higher level of solar energy penetration in Swedish energy system.

2- What will be the energy system configuration regarding solar PV?

Apart from the seasonality of prices in interconnected European electricity market, Sweden electricity supply's bottleneck is also affected by yet another important factor, which is the transmission capacity of the electricity grid. Due to the availability of significant hydropower potential and therefore hydrogeneration in the north of Sweden, while most of the population is in the southern part of the country, the transmission capacity, particularly in the events of high demand, acts as a bottleneck within the electricity supply chain creating a supply/ demand imbalance and could therefore pushes the electricity prices even higher (Lithner, 2021). A high penetration of renewable resources at the local grid is one of the solutions to enhance the sustainability of electricity supply chain. Solar PV is scalable, durable and has a relatively low LCOE for small scale solutions. An important characteristic of Solar PV application in a community is it's integrability; solar cells is integrated to buildings to provide electricity, with an ability to connect it to a hydrogen production unit in multi-families' buildings or in a collective unit for single- house buildings.

Furthermore, Solar cells are used by different consumers; residential, commercial, and industrial to shave power peaks; solar production is usually correlated to the peak in power consumption, which makes it a feasible option for many customers to generate power for self-sufficiency, trading to the grid or offsetting flow from the grid during high price durations. That been said, a scenario of a high

Solar PV penetration is expected, where decentralized generation and the rising share of prosumers are considered a significant contributor to the energy mix.

Traditionally, in Sweden, most of the solar photovoltaic investments and policy incentives have focused on distributed photovoltaic systems. The market in Sweden has so far almost exclusively consisted of decentralized, distributed off-grid and grid-connected systems, see figure 8. Yet, despite limited policy incentives and pessimistic forecasts, an increasing number of centralized photovoltaic parks have been commissioned and plans for substantial new capacities are communicated (Lindahl et al., 2022)

The unsubsidised levelized cost of electricity ranged from 27.37 to 49.39 €/MWh, with an average of 40.79 €/MWh which is lower than what are assessed for photovoltaic parks in some recent Swedish electricity system scenario studies. If the downward price trend continues, Sweden may face an unexpected expansion of photovoltaic parks. The estimated lifetime of various PV parks is projected to be between 20 to 45 years according to different interviews.

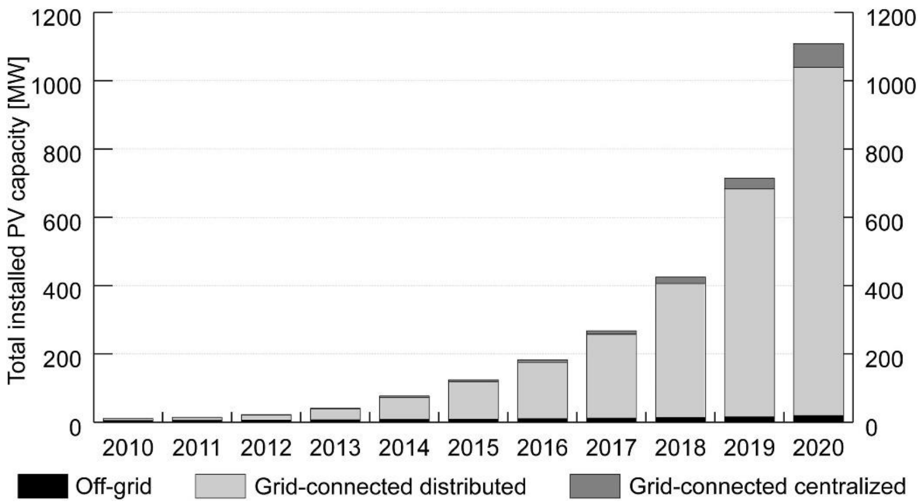

Figure 8 . Total installed PV capacity in Sweden (Lindahl et al., 2022)

Nevertheless, talking about the city Gothenburg, Gothenburg Energy in 2018 planned 2 large scale PV-parks, one close to Säve airport with a capacity of 5MW and one in Gårdsten with 1MV capacity. According to JL, nuclear will be dismantled in the next decade and that creates room for mor economic drive for renewable penetration and more centralized installations into the energy system in Sweden. Wind will gain the highest share among renewables and solar, as already stated, will take over in an order of 10% to 20% share of electricity production.

However, JL states that between wind and solar, there is no correlation on the cannibalization effect in Sweden's climate and these two sources of energy rarely produce at their peak range simultaneously. yet, on the cannibalization effect, correlation exists between solar energy and hydro power. On the other hand, Solar PV is generally peaking around mid-day, a time, in Sweden, associated with peak of demand and therefor the operation of peak generation. The solar generation would compete with these units and eliminate them when the generation of solar energy is high due to low marginal prices.

One can conclude that accelerating penetration of wind and solar power are generally correlated, there are, however, some variables that determine their share in the energy mix of a specific country during the renewable's take-off, i.e., energy potential, technical feasibility (Cherp et al., 2021). Sweden was able to increase the number of grid- connected solar PV systems by 50% between 2019 and 2020.

By the end of 2020 the installed capacity of solar PV modules exceeded 1 GW compared to 231 MW by the end of 2017 (SEA, 2021). Such a trend is likely to continue amid the direction of Sweden to achieve net zero (Lindahl, 2020).

Lastly, according to KH, there are many lessons that EU energy system can learn from that of Australian since the latter is ahead regarding the level of penetration of solar PV. The solar PV penetration in Australia is highly distributed and bottom up and has happened in a very individualistic level and the country has reached to the point that PV panels cumulatively are the biggest power plant during the peak hours. Due to oversupply by renewables and their variability, existing power plants have problems regarding curtailing the central ones and that has resulted in reliability issues for the transmission system. Therefore, Australia is at a point now that something called system low is occurring and instead of focus on the 'peak' that the network needed to adapt for and power plants were built for, there is a need to adapt networks to deal with 'system low' and frequency drop. Hence, there are solutions both on the market level and technology level that Australians are trying to investigate through constant trials and errors and system adjustments.

3- Who are the stakeholders involved for such system architecture?

Some of the future predictions give much weight to the individual initiatives to contribute to the penetration of Solar PV, such discussion is always related to the electricity prices and the economic incentive to have a small-scale system trading with the grid. According to RP, the demand from private persons have increased since more and more EV owners want to produce their own fuel. Today the tax reduction of 60 öre/kwh of the electricity private persons are producing and selling on the grid does not urge people to store their own electricity and buy when it's cheaper since the power transfer fee are needed to be paid when you're both selling and buying electricity. This means that the government benefits on this, but in the future maybe insensitive are coming to store your own electricity to buffer the power grid.

The commercial developers, in real-state sector for instance, on other hand are crucial stakeholders enabling the expansion of solar PV modules on the utility level with a variety of solutions for operation and finance. Sweden plans to reach net zero by 2045; the industry and energy sectors are aligning their electrification and Carbon neutrality objectives according to this strategy, therefore, they're determinant stakeholders when it comes to the solar PV diffusion at the utility level. All future predictions are based on some assumption regarding the policy makers visions and the policy instruments in place, therefore policy makers, legislative entities and supporting governmental agencies are important stakeholders.

According to KH, there is now an issue with the monopoly's (grid operator) access to the visibility of transmission lines in Australia which no other actor has access to such critical information to invest in services like providing communal storage and regulating voltage and frequency hotspots. Such information asymmetry has raised debates, there is so much push for market reform and the government is forcing the monopoly to publish something that is called the network map of opportunities. So private companies are queuing to install storage capacity and provide technical solutions due to transmission lines needs and this will potentially transform market and stakeholders and their zone of influence. According to JL, we will see wider spread of actors, not only as current traditional utility companies but more diverse range of ownership and service providers and in general more integration in other systems like with all the EVs coming online, more connection between electricity market and transport sector, and by shifting from fossil fuels, more connection with many industrial partners.

4- What will be the market attributed characteristics and challenges?

On the energy price, on one hand, one of the persisting challenges facing the Swedish and European energy market is the seasonal high electricity price associated with the high consumption levels in addition to temporal natural events, i.e., dry years, low wind speeds and low supply/ high demand of natural gas (The Economist, 2021). On the other hand, regarding the solar PV cost, according to (Feldman et al., 2021) there is approximately 6% and 3% reductions in residential PV-plus-storage benchmark and between 11.55% to 12.26% reduction in utility scale PV plus storage benchmark between 2020 and 2021 for DC-coupled and AC-coupled cases respectively. Most of these reductions can be attributed to reductions in the cost of PV modules and battery packs. Similar to the LCOE of stand-alone PV systems, the LCOE of PV- plus-storage does not focus on value of electricity but rather can help track improvements to all costs of a PV-plus-storage system over time (as opposed to just upfront costs), and the metric can provide limited comparisons with other dispatchable electricity generation technologies (e.g., natural gas).

According to JL, we will see much more fluctuating electricity prices in future, there are talks about changing the whole function of electricity market, that is currently pushed by nuclear and CHP actors and stakeholders in Sweden. They have been successful in persuading politicians, and it will change since they won't be the dominant actors in energy system in near future anymore. So, the emerging landscape in which some power sources are not being profitable anymore will affect the functionality of the market. Yet, rising shares of wind and solar in electricity markets around the world have led to concerns about their market integration at high penetrations. Several studies have found empirical evidence that electricity prices have decreased in markets as the share of variable renewable energy (VRE) has risen. The cause of the lower prices is the very low or zero marginal cost of wind and solar generators. This pushes out some of the more expensive generators from the market, and, since the price is usually set by the marginal cost of the last generator needed to satisfy demand, the prices are depressed during times of wind and solar generation. Lower prices lead to lower revenues for all generators, the 'merit order effect', but especially so for wind and solar generators, since their generation depresses prices exactly when they are generating most, an effect known as 'cannibalization' (Brown & Reichenberg, 2021). Therefore, as the share of solar PV increases in the system, the flexibility measurements should be deployed to preserve the efficiency of the market and optimize the market price

However, KH interprets cannibalization a terminology associated with the existing energy system and the market which values existing generation plants and assets whereas we are moving towards an energy market that there will be over-capacity in the system, and it will be inevitable to reform the market in which it is not only valuable to bid capacity but rather it will be very valuable to bid flexibility and associated services' provision.

Talking about market incentives, Sweden has, in contrast to many other European countries, never applied a feed-in-tariff scheme, which in general has been the favored and most effective policy for introducing new technologies (Polzin et al., 2019). The limited national policy incentives aimed at centralized PV parks or larger industrialized scale PV implementation represents itself in the self-consumption tax on over 500 KW of production too. The green certificate scheme is one of the policies used to facilitate a higher penetration of renewables into the electricity mix, it however favors the expansion of the generation technology that has better economic feasibility. In a country like Sweden, where the wind potential is significantly higher compared to the solar in terms of geographical and annual availability in addition to the lower LCOE, it seems that the green certificate scheme could promote a single technology which is wind in this case.

The tax system of today is not adapted to optimize PV production either. Companies that produce more electricity than they're using are given penalties in form of taxes. Therefore, it becomes cheaper to always use all or even more electricity than you produce instead of selling it. LH from Solkompaniet believes this system was an ineffective system but pointed out that the tax system is under an ongoing debate for change. For PV investments to increase, the tax system must encourage PV investments and not strangle them. Therefore, the tax balance must be optimized better.

According to ME, solar tax reduction is necessary to motivate utility scale instalments since for over 500 KW self-consumption, the tax is applicable on the production and makes it less interesting for larger instalments to occur. Moreover, according to JL there is no incentives for big industries' PV implementation due to applied taxes. Thus, there is a significant growth in smaller production scale in Sweden compared to the rest of the EU countries, Sweden governs a more conservative set of incentives when it comes to regulations for incentivizing the solar PV implementation.

JL believes, new subsidies and more economical support is needed for PV by making regulations easier or making it tax free for industries. On the house segment, there are subsidies which help growing PV integration and the growing market, however same growth has not occurred within the communal properties. But ME believes the solar PV market will grow significantly in the future due to increasing efficiency and consistently decreasing prices. Lastly, KH reflects on Australian energy system and its unexpected fast penetration of solar PV and consequential issues. Thus, she suggests that more conservative set of regulations can benefit countries like Sweden by providing enough time to prepare both on technology and market level for better adaptability to a renewably dominant energy system.

5- What will be the future technology of solar panels and storage options?

At present, the cost of the silicon based solar panels is decreasing and it is predicted that, this kind of solar cells are likely to stay popular for the future. A promising new technology for the highly efficient generation of photovoltaic electricity is silicon heterojunction (SHJ) solar cells. This cell type is viable for industrial production due to its high efficiency, simple processing, and high temperature stability, in addition to the use of thinner wafers (Itten & Stucki, 2017). Another promising technology for cost efficient solar electricity generation is perovskite solar cells (PSC). PSC can be combined with first- and second-generation solar cells in either monolithic 2-terminal or stacked 4-terminal tandem solar cells with high efficiency. The combination of the SHJ and PSC technologies in multi-junction tandem cells has the potential to achieve a conversion efficiency of up to 30%, significantly reducing the area required for photovoltaic electricity generation (Itten & Stucki, 2017).

According to ME, there is a high effort to make the upcoming technologies cheaper with higher efficiency at the same time. JL states that what we see now is the instalment of the 2nd generation solar cells mostly but the 3rd generation of heterojunction in silicon is starting to be commercialized and the maximum efficiency will increase from current 21% to 24% at least. There are factories both in China and in North Europe which are producing the 3rd generation and it will come online soon actually and it is starting to gain penetration in overall PV market. Silicon based bifacial modules global market shares are also expected to reach a 60% market share in 2029 globally, due to generation gains at a low additional cost. For utility scale systems, it is reasonable to believe that bifacial modules become the preferred technology within 2024 (Danish Energy Agency, 2019).

Stationary energy storage on the other hand is a necessary compliment for renewables' integration into the transmission lines and is very dependent on how fast costs decrease. From 2015 to 2018, prices declined due to developments in lithium-ion battery technology. However, for finding the best battery for solar cells we need to consider some factors apart from price, such as: Energy and power capacity, depth of discharge, solar battery life warranty and round-trip efficiency. From JL point, storage in Sweden will be more applicable to small scale production (residential sector and small commercial sector) and for larger scale PV instalments like PV parks, there will be more voltage and frequency regulation solutions. This is mainly driven by economic incentives and benefits as increasing self-consumption part of what you produce in smaller scale whereas not much economic gain for big industries to connect to battery for storage. In 5 years, there will be batteries for big PV centralized parks though. However, they will be mainly used for voltage and frequency regulation and control rather than the actual storage. However, KH argues that storage will be much of a valuable service to bid on the future reformed market since there is no mechanism on the existing market for that end; to look at storage as a source of generation. Only in a reformed energy market it will make commercial sense for a more widespread use of storage technologies and batteries.

Moreover, on global level, more stationary storage will be built and installed in connection to solar parks. According to KH, In China, no centralized renewable plant can be connected to grid system unless it is supplemented with proper storage and battery system. According to ME, Lead Acid batteries are the most common type of batteries for storage of electricity from solar cells. These types have been used for many years due to their reasonable price. However, LIBs are taking over all over the world partly because of their dominant use in EVs. Lastly, KH argues that there are huge investments on different types of batteries (particularly vanadium-based battery technology for stationary purposes) and hydrogen fuel-cell in current Austrian energy system and government is providing huge funds for R&D to utilities for storage related programs.

6- How much land is needed? And what are the environmental impacts associated with solar PV and required resources?

On the space requirement and land use, the module area needed to deliver 1 kWp of peak generation capacity equals 5.3 m^2 by today's standard PV modules. For modules on tilted roofs, 1 m^2 of roof area is needed per m^2 of module area. Modules on flat roofs and modules on ground will typically need more roof and land area than the area of the modules itself, in order to avoid too much shadowing from the other modules. Large PV power plants can be installed on land that otherwise are of no commercial use (landfills, areas of restricted access or chemically polluted areas). PV systems integrated in buildings require no incremental ground space, and the electrical inter-connection is readably available at no or small additional cost (Danish Energy Agency, 2019). Moreover, improvements in PV technologies and increasing efficiency will significantly reduce the area required for photovoltaic electricity generation (Itten & Stucki, 2017).

Aesthetic concerns may limit the use of PV in certain urban environments and in the open space when the visual impact is unacceptable. Gothenburg municipalities planning office has started developing a map with areas that cannot be used for more essential usage, examples of targeting areas are areas behind highways, roads, and landfills. Those areas are for now unused which can be used for solar implementation. Even if some of these areas are not optimal in consideration of solar radiation switches can be a good option. As technology develops and efficiency increases, panels in optimal places can change to the new versions and the old ones that degradation has not taken out can still run for many years to come in those targeted areas. According to LH there is misunderstandings that to reach Sweden's renewable energy demand panels needs to be everywhere and therefore outcompete both farming land and forests, but PV installations would only need to be a small part of Sweden's total area.

Göteborg Energis has for now two solar parks Solevy and Utby. The technological development is advancing in both parks the installed capacity is 5,5 MW but Solevy has according to RP 20 000 panels and Utby 15000 panels but still the capacity is the same. The efficiency of the old panels is around 280-300W but the newer at Utby has 400-450W. The new ones are more expensive but in the same way land can be saved since the same efficiency can be fulfilled with less panels. 15000 verses 20000 is a 25% land save. Another land saving method is to mix solar and wind in parks, since the fuse are dimensioned for the maximum capacity, there are in the majority of time not that much energy produced. In a test LH talked about they installed 9000 kwp of wind and 3000 kwp of solar, with a grid fuse of 3000kwp. To run this installation on the same fuse would only give a 5% capacity loss since wind and solar in most cases have different production curves, a 30% solar installation regarding to the wind installation would be the best mix to maximize fuse output and get a steadier energy flow to the grid.

The environmental impacts from manufacturing, installing and operating of PV systems are limited yet this is not the case for stationary batteries which require many scarce and critical metals including Cobalt, Nickel, Lithium and Manganese which have consequential environmental impacts. PV does not use any fuel or other consumable. Energy payback time (EPBT) is dependent on multiple factors such as PV technology type, type of manufacturer and geographical location. The current average EPBT of a typical crystalline silicon PV system in Europe is 1 to 2 years (Danish Energy Agency, 2019).

On the resource availability and environmental impacts, materials abundancy (In, Ga, Te) is of concern for large-scale deployment of some thin-film technologies (CIGS, CdTe). Some thin-film technologies do contain small amounts of toxic cadmium and arsenic but all PV modules as well as inverters are covered by the European Union “Waste from Electrical and Electronic Equipment" (WEEE) directive, whereby appropriate treatment of the products by end-of-life is organised. The best perovskite absorbers contain soluble organic lead compounds, which are toxic and environmentally hazardous at a level that calls for extraordinary precautions (Danish Energy Agency, 2019).

Regarding recycling, today processes are not mainstream implemented, both because it is not economically profitable before ramping up to large quantities of panels. The last years the PV implementation has increased a lot and with a lifetime of 25-30 years there is still a few years to ramp up recycling plants, even if some panels become broken beforehand, yet the recycling infrastructure has not been prioritized. When recycle systems are up and running both the economic and environmental benefits increase. Germany is future ahead in recycle development compared to Sweden so Sweden will probably look on how Germany is doing with the recycle process RP believes.

7- What will be the interplay between future transport system and the state of renewables and solar PVs?

Transport accounts for around one-fifth of global emissions, with road travel accounting for fully three-quarters of that amount. Electric vehicles (EVs) are one of the most promising technologies for reducing emissions in global transportation, but the benefits they bring depend on the provenance of the power they run on. According to the International Energy Agency (2021), the number of electricity-powered passenger vehicles on the world’s roads could surpass 250 million by 2030, while electric buses and other mass transit vehicles could number well over 10 million. By 2030, the amount of electricity needed to power all the EVs will be a whopping 640TWh. According to trafikanalys (2020), there are almost 5 million cars in Sweden, imagine in a future society where all those cars are BEVs, then there will be 500 MWh of buffer electricity. This vehicle to grid and grid to vehicle electricity transfer will make a huge grid impact, both as a solution and a challenge.

This creates a major opportunity to position EVs as one of the biggest drivers of renewable electricity. Besides, the EU battery manufacturing industry is kicking off thanks to electrification of automotive industry, and one of the goals is to establish a sustainable manufacturing landscape which also feeds advancements in stationary storage technologies. Volvo Cars and Northvolt have selected Gothenburg to establish a new 50 GWh battery manufacturing plant which will commence operations in 2025 to reach strategic ambitions in electrification.

According to PV magazine (2022), plans to re-establish a thriving European solar manufacturing base are underway. Johan Lindahl, secretary general of the European Solar Manufacturing Council declares in an interview that COVID-19 and now the aggression from Russia have clearly demonstrated dramatically the problems that follow losing important value chains for important and strategic products and services. As PV are about to become a major cornerstone in the European electricity mix, PV manufacturing becomes an important issue of EU´s strategic autonomy. He believes more integration in other systems like with all the EVs are coming online, more connection between electricity market and transport sector, and by shifting from fossil fuels, there will be more connection with many industrial partners.

Another interconnected aspect of EVs and renewables can be addressed by variability management through demand management which is considered as an energy systems' bottom-up regulation strategy instead of top-down planning. According to KH, such bottom-up approach on the technological level incorporates islanding neighbourhoods and certain communities so if there is any surplus in an island, it does not affect the rest of the grid system. Besides, by equipping neighbourhoods with community batteries to become self-sufficient they can manage micro-grids to be coordinated with the transmission system. EVs then can play a major role in such embedded networks whereas now in Australia, there are private companies which provide behind the meter services and optimization tools which connect the circuits in people's houses to real time monitoring of them, either to provide suggestions for optimizing the use of energy or automatize certain things in houses that use their own PV generation among which are EVs smart charging strategy.

6.Conclusion and Future Work

To fight climate change and to strengthen the strategic sovereignty of the European energy supply, the deployment of renewables must accelerate. PV electricity contributed to about 6% of the European Union's electricity demand last year (2021) and is now one of the key components in the electricity mix. With the proposed EU 40% renewable energy target by 2030 (which may be even 55% as currently discussed) PV needs to stand for about a cap of 30-40% of the electricity production in the future (PV magazine, 2022).

In Sweden, there is an urge to accelerate more renewables into the energy system to reach targets. Such discourse has enhanced so fast that one out of four prospective scenarios for 2035 that Swedish Energy Agency had developed in 2016 has already been expired since the number of grid-connected PV systems increased from 10,000 to 44,000 from 2016 to 2019 in this country with a dramatic drop of installation and solar panels prices. It is also important to illustrate the solar PV penetration into the energy system not as an isolated phenomenon, but rather highly connected to the rest of the energy system, whether regional, national and trans-national. Sweden for instance has a common Nordic electricity market with cables and lines to the neighbouring countries. It is thus part of the international energy market. Spatial and regional planning, land and/or grid ownership, electricity market, transport sector and different legislations, regulations and policies play an important role in that ground.

Thus, due to upcoming landscape change, complexity of energy system and its externalities and unpredictable transformations in energy market, transportation, stakeholders and their zone of influence, there could be no certainty on what exact route the future energy system in Sweden will unravel. Such uncertainty though would be the main drive for more elaborative scenario analysis and research and development. A complementary work would be to examine the flexibility measures associated with different scenarios and their impact on the technical and social system. Furthermore, the pathways to achieve the level of solar energy presented in this work could be further explored to determine the dynamic characteristic of the solar diffusion in Sweden. As Kristina Hojckova described via insights from Australian energy system, it is all about trials and errors and constant adjustments on both bottom up and top-down levels

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