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Opportunities for Large Scale Solar Photovoltaic Systems in Swedish Multi-family Housing

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***Abstract*—Sweden is well known for its leadership in sustainability and energy system transformation; however solar photovoltaics have typically been left out. Recently, small residential systems have been gaining support through capital rebate subsidies and a number of utilities have begun offering modest net metering or feed-in tariff programs. There is a component of the Swedish residential sector with larger and more interesting potential; cooperative multi-family housing.**

Cooperative ownership structures are common in Sweden, accounting for nearly 20% of the total housing stock and growing at a compound rate of 2% per year. Cooperatives are considered residences except they have the possibility to install commercial sized systems up to 2.5 MW_p in size. This means they can leverage greater economies of scale over detached homes making them a more interesting target for solar installations. While the system is commercial in scale, features of commercial development like complicated financing, tax structures, and renewable energy credit markets are just as daunting to a cooperative as a villa owner.

This study is the introduction to a three year research program to be conducted from the cooperative point of view of installing solar PV. Included is a review of the current technical, economic and policy conditions in Sweden, a brief case study and proposals for future studies. Simulations are performed using the System Advisor Model from NREL. Results show that the levelized cost of energy can be competitive with retail rates, but maximized deployment may require some form of preferential metering.

Keywords – photovoltaic, multi-family housing, cooperative housing, Sweden, community solar, economics, review

I. INTRODUCTION

Solar photovoltaic (PV) technology has seen accelerated development since its initial terrestrial deployment in the 1970's. Increasing fossil fuel prices combined with concerns of climate change and carbon dioxide emissions have ushered in a new wave of research focused to improve the value of solar energy. The goal is to make solar PV a competitive energy source in the open market and usher in a new era of sustainable energy.

Sweden is well known for its leadership in sustainability and transforming its energy system, however solar energy is often disregarded. The extreme northern latitude can instill images of long dark winters, however the long summer days are an excellent opportunity. As shown in Figure 1, the majority of the Swedish population lives in areas with similar annual solar resources to Germany, which has the most installed capacity of solar PV per capita in the world [1]. To exemplify the differences; at the end of 2012 Sweden had 24 MW_p of total solar PV capacity, whereas Germany has over 32 GW_p [2]. Over the past decade across numerous countries, favorable installation policies combined with increased investment in research and massive scales in manufacturing have created a feedback loop of progressively lower solar energy prices. When compared against Sweden's steadily increasing electricity prices, the opportunity for cost effective solar energy needs to be considered.

Cooperatives, known in Sweden as bostadsrättförening, are multi-family residential organizations governed by a board of directors and account for 20% of the current residential building stock [4]. They range in size from a few apartments in a single building to several hundred on a large campus. Communal energy services, such as heating, outdoor lighting and laundry are handled by the board and paid for by a monthly fee from each owner. The large roof areas and energy demands lend to greater economies of scale, while the larger community provides financial stability for lower lending rates, creating a good opportunity for solar PV.

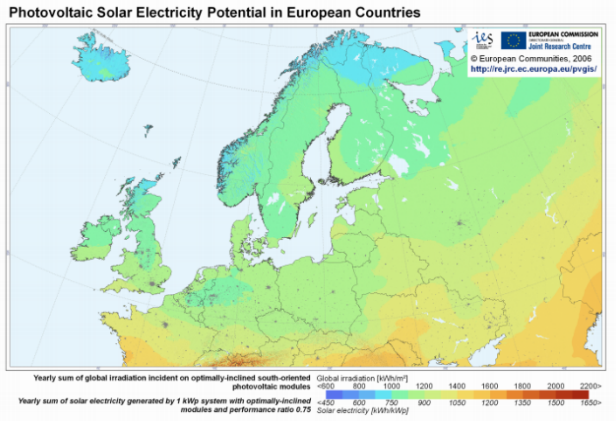

Figure 1. Annual solar irradiation on a tilted surface in Europe [3]

This paper will review the state of PV technology as of April 2013 and how it relates to cooperatives in Sweden. The focus will be on technology that is commercially available or may become available in the near to mid-term (one to five years) such that it is practical for planning. There is also a review of the current markets and incentives for solar energy. The most interesting technologies and policies for Swedish cooperatives will be determined, the unknown variables that need to be understood are identified, and recommendations for further research will be made. Also included is a preliminary case study as an example cooperative system.

II. PV SYSTEMS IN SWEDEN

PV use in Sweden has traditionally been dominated by small, off-grid systems for summer cabins or remote equipment. However beginning in 2007, grid connected installations began to grow rapidly and now make up the largest part of the small Swedish market. In 2012, 8.44 MW_p of capacity was installed, 90.3% of which was connected to the grid. PV represented 0.76% of all new generation capacity installed in 2012, and was responsible for 0.01% of all electricity generation. [5] Figure 2 shows the cumulative installations for Sweden over the past 20 years.

A. *Module technologies*

Like most of Europe, crystalline silicon modules dominate the Swedish market. There are a few suppliers that offer thin film, but it is uncertain what benefit these modules can have for a rooftop system. In a typical villa installation, roof space is limited such that the higher efficiency crystalline modules are necessary to get the desired system output. However, the available roof space on a cooperative may make thin film options more interesting so long as racking costs are kept down.

B. *Inverter technologies*

The key task of the inverter is to convert electricity from DC to AC, but there are two critical functions it performs on either side of the conversion; maximum power point tracking (MPPT) and grid synchronization. An MPP tracker is capable of adjusting the resistance (and thus the voltage) in the system to keep the power output as high as possible. An MPPT is not necessary for the function of the system, and not all inverters have the feature. However, the benefits far outweigh the costs and MPP tracking is nearly ubiquitous.

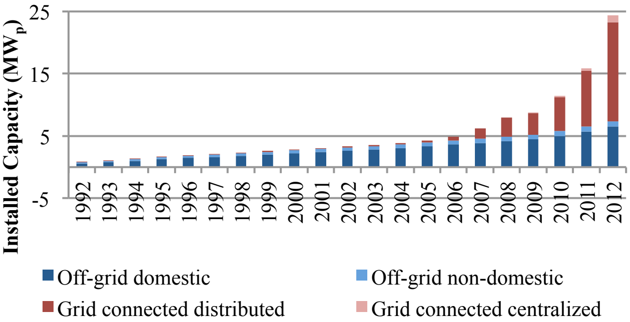

Figure 2. Cumulative PV installations in Sweden [5]

Most inverters in Swedish rooftop systems are of the typical central type, where all of the modules are wired into a single unit (or several units in large systems). Inverter strategy has been a dynamic topic in the past several years with the rise of commercially viable micro-inverters. Localized shading of just a single panel will reduce the output of the entire array by more than the percentage of shading, making complicated roof areas prone to excessive losses. Micro-inverters are placed on every (or every other) panel, meaning each module has its own MPPT. This can increase instantaneous system output by 3% to 100% percent depending on the shading and system [6]. Until very recently the largest disadvantage has been cost, however initial cost differences are now low and expected to go lower with continued research. This technology is very interesting for rooftop systems, and could be beneficial for cooperatives with many ventilation fans, vent pipes and/or complicated roof structures.

C. *Storage*

Low-cost storage is considered by many to be the key to unlocking the full potential of renewable energy. It comes in many forms for many applications, and the research and development is very active. Battery storage has been used in off-grid PV systems for decades, and surprisingly the technology is nearly the same today. Current research into battery storage is largely focused on grid scale and electric vehicle systems, the latter which will be most interesting for residential energy generation. Lithium based variants are the most commonly researched; with lithium-air showing potential as one of the next big steps forward [7].

Storage in grid connected systems has not typically proven to be economically feasible. However, the arrangement of cooperatives in Sweden is rather unique, and lends itself to interesting community based solutions. One such option is a cooperative owned, electric car sharing service. In many areas, parking is space constrained and difficult to manage, thus a shared resource may cut down on some tenant's need for a privately owned vehicle. Additionally, there are government subsidies available for decarbonizing the transportation sector, opening the door for electric vehicles. A small fleet of electric vehicles on campus could be used as a storage vessel for the PV system, potentially solving three problems at once. Vehicles would need to be used predominantly for local errands, preferably in the evenings, and not for daily commutes.

D. *PV/T hybrid systems*

PV panels only convert around 10% to 20% of the total solar energy hitting them to electricity. Most of the remaining energy is converted to heat. As temperatures in a PV panel rise, accelerated degradation and loss of efficiency on the order of -0.5% per °C for crystalline silicon [8] and -0.25% per °C for thin films occurs [9]. Cooling is thus an important consideration in system design and is typically handled with an air gap between the modules and roof surface. Significant research has gone into capturing that thermal energy for useful work, and hybrid electrical and thermal modules are known as PV/T [10]. There are numerous technical and economic challenges to make PV/T work in the market, and penetration has thus far been limited. There are a few Swedish companies designing and manufacturing concentrating PV/T equipment; however their deployment in the local market is primarily for demonstration.

There are three primary fluids used to capture heat from a PV module; air, water and refrigerant. An air based system would compete with a heat recovery system, the latter of which is valuable during much more of the heating season. Water based systems suffer from a coordination of energy supply, where the objective of the thermal system is to increase water temperature and the PV cells need cooler temperatures. Successful water based PV/T installations are likely to happen where the primary energy is heat and the opportunity is taken to extract some electricity as a bonus, which does not align with the objectives of this project. Cooling the PV panels with refrigerant can be done via a wide variety of systems. When used in conjunction with a ground source heat pump, the PV/T panel can be cooled and the boreholes heated, improving the efficiency of both systems. Additionally, many Swedish residences already use ground source heat pumps, making adoption easier.

E. *Building integration*

A powerful idea being promoted by sustainable energy advocates is the concept of buildings as power plants, where generation is decentralized to the point of use and thus significant research has gone into incorporating solar PV into building envelopes [11]. Racking is by far the most common method; however a number of concepts offer improved aesthetics and multiple functionalities. More deeply integrated options include; roof tiles, facades and windows. Cost tends to be the limiting factor in widespread adoption. Unless a cooperative is only interested in solar PV where aesthetics are preserved, then traditional racking will be the default mounting method for this project.

F. *Costs*

Final installation cost depends on a wide variety of local factors. For example, in the U.S. in 2012 the cost of a typical rooftop residential installation was double the average German installation due entirely to balance of system and soft costs [1]. In Sweden, small do-it-yourself packages can be purchased from Norden Solar for as low as 13.2 SEK/W$_p$ [12]. Installed systems on villas from Vattenfall, Fortum and DinEl can be had for at 21.23 SEK/W$_p$, 27.69 SEK/W$_p$ and 20.83 SEK/W$_p$, respectively (before VAT and potential 35% subsidy) [13][14][15]. Roof mounted commercial systems are known to have a 30% lower installation cost than small residential systems [5], which makes installing large systems on cooperatives interesting.

III. SWEDISH ELECTRICITY MARKET

After many years of largely stable and low electricity prices, the market has undergone a series of significant changes and has become increasingly variable. In 1999, the market was deregulated such that generation and final delivery were separated. In 2002, the renewable electricity trading system (REC) came online followed quickly by the EU emissions trading scheme (ETS) in 2004. There has also been a reversal in policy to phase out nuclear power and construction of new international transmission lines.

A. *Rates*

Even with all of the changes to the market, weather is believed to be the most important variable driving electricity prices [16]. Hydropower is about 45% of the electricity production (nuclear ~40%, thermal[1] ~11%, wind ~4%), meaning dry years can significantly restrict supply. Likewise, cold winters drive up demand because a large amount of heating is done with electricity. The average spot price for wholesale electricity in 2012 was 285 SEK/MWh, with daily averages ranging from 62 to 900 SEK/MWh [17]. Figure 3 reports average January electricity prices (adjusted to 2010 SEK), where there have been spikes in 2003, 2010 and 2011 due to weather driven demand/supply imbalances. It is worth noting that wholesale electricity is only 20-25% of the retail price and taxes are over 40%. This means there is a strong incentive for the solar system owner to use as much electricity on site as possible, and consequences for the government budget as distributed solar installations increase.

B. *Incentives for PV*

In addition to the EU wide energy goals for 2020, the Swedish government has committed to a number of additional goals including an increase in renewable energy production. This has led to a number of incentives being established for PV.

1) Capital rebates: Capital based rebates are payouts intended to reduce the high initial costs of a solar system such that they are more accessible and provide a better return on investment. Sweden's history with solar subsidies has been mostly focused on capital rebates, with discounts as high as 70% between 2005 and 2007. Current policy allows rebates of up to 35% of total installed cost (1.2M SEK maximum subsidy) for eligible systems costing at most 37,000 SEK/kW$_p$ for PV and 90,000 SEK/kW$_p$-el for PV/T systems [18]. There is a fixed amount of money for the program, which for 2013 is set for 107.5M SEK, nearly double from the 57.5M SEK in 2012 [19]. The program is extremely popular, and waiting times for payment are usually long, as much as two years [5].

2) Feed-in Tarrifs: On a national level, there is no government imposed feed-in tarrif like in many other EU countries. However, the deregulated market allows utilities to offer customers special rates for excess generation fed back into the grid. Offers tend to only be extended to micro-producers (systems under 10 kW$_p$), and usually require the owner to be a customer of the utility they wish to sell to. Tarrifs range from 0.8 SEK/kWh to 1.5 SEK/kWh from some of the smaller utilities. The three largest utilities, Vattenfall, Fortum and E.On, which make up 80% of the market, offer the Nord Pool spot price minus a small fee [5].

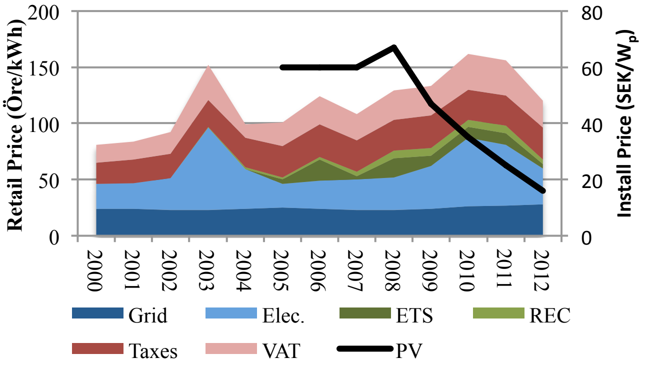

Figure 3. Average retail electricity and installed PV prices [16][5]

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[1] Thermal power plants are typically CHP, where 60%-75% of the primary fuel is biomass and the rest are fossil fuels [14]

3) Net metering: Like the feed-in tarrif, there is no national net metering law in Sweden but some utilities have taken it upon themselves to offer their own program. Specifc programs vary considerably and can be net over a daily, monthly or annual time frame. It is likely however that these programs will be revised as there is the potential for a national law to be introduced. In the summer of 2013, a proposal in the Official Reports of the Swedish Government (Statens Offentliga Utredningar) suggests a tax rebate instead of a net metering program to avoid violating EU VAT laws. The value of the rebate would be based on the retail price and amount of electricity fed into the grid from a PV system in a given month [20]. Net metering in principle has political support, however opponents argue this method is overly complicated and will require high administrative costs. Additionally, the proposal limits systems to 43.5 kW and smaller, making it less attractive to larger cooperatives.

4) Renewable energy certificates: A more market based approach is a renewable energy quota system, where a desired volume of renewable electricity is determined and the market sets the price. Established in 2002, Sweden (which joined markets with Norway in 2012) currently have a target to produce an additional 26.4 TWh of electricity from renewables between 2012 and 2020, which corresponds to about 10% of the total generation of both countries. Solar systems qualify for the program; however it is largely beneficial for utility scale producers. Building owners do not usually participate because they have relatively low excess generation compared to the additional overhead, however cooperative sized installations may be more interesting. Since May 2003 when the market opened, certificate prices have fluctuated between 150 SEK/MWh to nearly 400 SEK/MWh, and in 2013 have been between 178 and 223 SEK [21].

IV. FUTURE RESEARCH TOPICS

While most of the technologies and systems reviewed have been deployed in considerable volumes in other countries, Sweden is still relatively new to solar PV, leaving the door open for questions about how these systems will perform. This is particularly true in the case of cooperatives, where very few (if any) large scale installations have been made. So the first question that arises is how does PV production compare to the energy demands of a cooperative? This is a critical question because it will determine how much and when there is overproduction. Then there is the question of what to do with the overproduction? Should the building load be increased so it can be used on site? Can it be effectively stored? Can it be distributed to the individual apartments? Should policy promote supply to the grid? Should the PV system stay off the grid? How can or should cooperatives benefit from policy support? There are many potential paths, but determining which ones are financially, politically and socially feasible is the basis of the proposed studies.

A. Solar energy supply in cooperative housing

The first task of the project is to determine some foundational information about solar energy supply and how it relates to cooperatives. Desired outcomes will be an understanding of; general building construction and shading effects, performance of various technologies in the Swedish environment, determination of typical load patterns for a cooperative and the apartments within, the balance of supply and demand of each solar technology with the cooperative and the levelized cost of energy for each system. Potential system sizes will be approximately 100 kW_p to 2000 kW_p. The outcomes of this study will provide a broad overview and understanding of Swedish solar PV systems, determine the volume and timing of electricity generation and highlight particular technologies to use in subsequent studies.

B. Innovative metering

In most cooperatives, the HVAC and communal energy services are handled by the cooperative and paid for with a monthly fee. Any electricity used inside the apartment is metered separately, which allows each tenant to purchase electricity from a supplier of their choosing. For a cooperative interested in installing the most possible solar PV, the actual on-site electricity usage could be considered rather than just the communal account. Therefore it is interesting to understand the excess electricity generated by a PV system and compare it to the demand from the aggregate apartments. Potential schemes will be introduced that could allow cooperatives to sell this electricity on-site which may permit higher revenues over grid sales and lower rates for tenants.

C. Financial incentives and public policy

Once the dynamics of building mounted solar PV in relation to building demand and the grid are understood, economic models can be constructed. Comparisons will be made with the current incentive programs and several alternatives in net metering and feed-in tariffs and evaluate them from several points of view. The objective is to gain an understanding of what types of policies will be most beneficial for cooperatives, utilities and society from an economic and technical perspective. Conclusions will require assumptions/inputs about what the stated goals are of solar PV and energy policy as a whole in Sweden, primarily the transition to a sustainable energy system.

D. The role of electric vehicle storage

When considering the Swedish energy system as a whole, electricity generation is possibly the most environmentally friendly sector from both an air quality and carbon emissions standpoint. Transportation, however, is still largely reliant on fossil fuels. Cooperatives provide an interesting opportunity to deploy electric vehicles (EV) in conjunction with solar PV due to its multiple benefits as electricity storage and shared transportation. Therefore developing a car sharing scheme for cooperatives which will double as excess generation storage could benefit a PV system. The technical requirements will be determined and the economic performance evaluated against the business as usual scenario as well as grid connected systems.

E. Solar PV/T combined with borehole storage

The benefits of actively cooling a PV module are well known, however capturing the heat for productive and economical use has proven difficult. The combination of a hybrid solar PV/T system in conjunction with the boreholes of a ground source heat pump is promising. A simple solution is to run a cooling loop between the PV/T modules and the boreholes of the heat pump. The pure technical benefits of the system as well as the economic considerations will be studied.

F. Propogation of solar PV in Sweden

Energy policy design is often the balance of the will of the people, the will of industry and the unique role of government as a catalyst to change. The opinions of various actors and impacts of policy can be used to estimate the potential uptake of solar PV in Sweden. Surveys will be created for producers, consumers and industry advocates to gauge the level of interest against alternatives (e.g. willingness to pay for environmental benefits, investment interests, etc.). With survey feedback and geospatial data (e.g. suitable roofs, ability to pay, etc.), a map series forecasting the installations of solar PV over time given various policy inputs can be created to identify where and when solar energy may be of interest for Swedish cooperatives. This information is helpful for policy makers, grid operators, utilities and installers of solar energy.

V. CASE STUDY: SAGOGÅNGEN

A close working relationship with Riksbyggan has opened the opportunity to use several specific cooperatives as case studies in this work. One of the cooperatives, Sagogången, has an accelerated schedule due to a planned roof replacement, thus providing preliminary results. They are being presented here to provide a more concrete understanding of the conditions in Sweden for this project.

A. Description of the cooperative

Sagogången is a large cooperative with 506 apartments on the northern side of Gothernburg in western Sweden. The campus consists of 11 buildings with two or three floors, covered balconies on both sides and exterior stairwells. The total condition space is 38,914 m^2, including communal spaces. There is approximately 17,000 m^2 of available roof space with a 15° pitch, of which 24% faces south, 28% faces west and 25% faces east.

B. Description of the model

All simulations are performed using the System Advisor Model, known as SAM. SAM has been developed by the U.S. National Renewable Energy Lab in partnership with Sandia National Labs and the University of Wisconsin. It uses some of the most powerful solar modeling tools available and combines them with a large selection of financial analysis tools [22].

C. Inputs and assumptions

The hourly load profile used for the cooperative has been created using building simulation software EnergyPlus, and then scaled to match the known monthly consumption provided by Sagogången. Future work will use metered hourly data. The electricity usage consists of HVAC pumps and fans, outdoor and communal lighting and laundry.

Using best available data for estimates, cost for modules, inverters and balance of system are estimated to be 16.73 SEK/W_p plus 25% VAT. The lifetimes of the modules and financing are 30 years and inverters 15 years, leading to a simulation length of 30 years. 100% of the cost is borrowed at 4%, with a 1.5% inflation rate and 4% discount rate. The price of electricity is 1.3 SEK/kWh and is set to grow at 2% per year, much less than the average annual rate since 2000.

D. Basecase: Current Conditions

This system has been simulated under the market conditions which currently exist in Sweden for large PV systems. The method allows the sale of excess electricity to the utility at the hourly wholesale spot rate. This is a very difficult number to predict as the Swedish market has been erratic in the past decade; therefore 2012 is used as a sample year. The prices have been divided into nine tiers as is accepted by SAM, rather than actually hourly values. Results for this system are reported in Table I and Figure 4.

E. Alternative one: Capital Subsidy

Technically, this system is identical to the one proposed in the base case. The difference is the application of the 35% capital subsidy currently available until 2016. Results for this alternative are reported in Table II and Figure 5.

F. Alternative two: Net metering

In this alternative, the capital subsidy is removed and net metering is applied. Net metering is on a monthly basis, meaning that excess generation at the end of a monthly billing cycle is not carried over to the next month. Results for this alternative are reported in Table III and Figure 6.

TABLE I. RESULTS FOR THE BASECASE: CURRENT CONDITIONS

System Parameters	
Size	98.5 kW_p
Total Cost	2,018,227 SEK
Total Module Area	613 m^2
Percentage of South Facing Roofs	16.8%
Percentage of All Productive Roofs (E, S, W)	5.2%
Results	
Total Annual Production	91,707 kWh
Percent of Annual Demand	16.4%
Discounted Payback	25.0 years
Net Present Value	259,246 SEK
Levelized Cost of Energy (real)	1.35 SEK / kWh

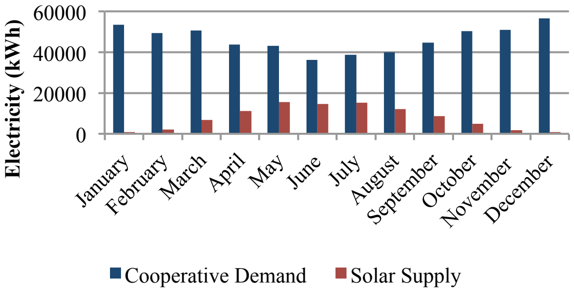

Figure 4. Monthly demand and baseline PV system supply

TABLE II. RESULTS FOR ALTERNATIVE ONE: CAPITAL SUBSIDY

System Parameters	
Size	98.5 kW_p
Total Cost	1,311,847 SEK
Total Module Area	613 m^2
Percentage of South Facing Roofs	16.8%
Percentage of All Productive Roofs (E, S, W)	5.2%
Results	
Total Annual Production	91,707 kWh
Percent of Annual Demand	16.4%
Discounted Payback	16.6 years
Net Present Value	849,036 SEK
Levelized Cost of Energy (real)	0.96 SEK / kWh

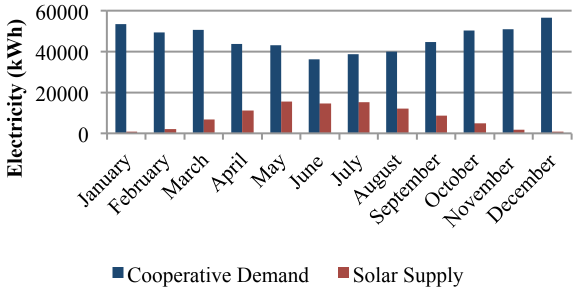

Figure 5. Monthly demand and alternative one PV system supply

TABLE III. RESULTS FOR ALTERNATIVE TWO: NET METERING

System Parameters	
Size	248 kW_p
Total Cost	5,099,932 SEK
Total Module Area	1544 m^2
Percentage of South Facing Roofs	42.3%
Percentage of All Productive Roofs (E, S, W)	13.1%
Results	
Total Annual Production	231,108 kWh
Percent of Annual Demand	41.4%
Discounted Payback	25.0 years
Net Present Value	786,246 SEK
Levelized Cost of Energy (real)	1.36 SEK / kWh

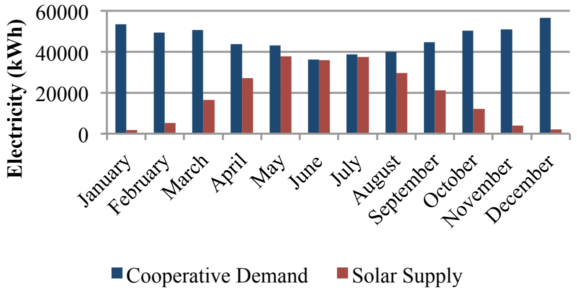

Figure 6. Monthly demand and alternative two PV system supply

VI. CONCLUSIONS

The previous sections reviewed a number of PV technologies as they apply to building applications and identified those of particular interest to cooperatives in Sweden. The cooperatives are financially conservative, so economic viability will be a guiding force in the technologies chosen for research and ultimately final recommendations. In light of environmental conditions and the pursuit of sustainable societies, there is also an interest in deploying as much solar energy as possible. Therefore, methods to economically maximize solar potential will be sought through much of the future work. A preliminary case study was presented to demonstrate how solar PV fits into the cooperative's energy demand and the roof potential.

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REFERENCES

[1] J. Seel, G. Barbose, and R. Wiser, "Why are PV prices in Germany so much lower than the United States?," LBNL, Berkley, CA, 2013.

[2] G. Masson, "PVPS Report: A snapshot of global PV 1992-2012," IEA, Paris, France, Rep. IEA-PVPS T1-22:2013, 2013.

[3] M. Šúri, T.A. Huld, E.D. Dunlop, and H.A. Ossenbrink, "Potential for solar energy generation in the European Union member states and candidate countries," *Solar Energy*, vol. 81, 2007, pp. 1295-1305.

[4] Statistica centralbyrån. (2013, March 05). *Sharp decrease in conversion of rental dwellings*. Available: http://www.scb.se/Pages/PressRelease____335521.aspx

[5] J. Lindahl, "National survey report of PV power applications in Sweden - 2012," Ångström Solar Center, Uppsala University, Uppsala, Swe., Mar. 2013.

[6] C.R. Sanchez Reinoso, D.H. Milone, and R.H. Buitrago, "Simulation of photovoltaic centrals with dynamic shading," *Applied Energy*, vol. 103, 2013, pp. 278-289.

[7] S. Fui Tie and C. Wei Tan, "A review of energy sources and energy management system in electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 20, 2013, pp. 82-103.

[8] Z. Ye, A. Nobre, T. Reindl, J. Luther, and C. Reise, "On PV module temperatures in tropical regions, *Solar Energy*, vol. 88, 2013, pp. 80-87.

[9] N. Strevel, L. Trippel, and M. Gloeckler, "Performance characterization and superior energy yield of First Solar PV power plants in high-temperature conditions," *Photovoltaics International*, 2012.

[10] T.T. Chow, "A review on photovoltaic/thermal hybrid solar technology," *Applied Energy*, vol. 87, 2012, pp. 365-379.

[11] M. Manfren, P. Caputo, and G. Costa, "Paradigm shift in urban energy systems through distributed generation: Methods and models," Applied Energy, vol. 88, 2011, pp. 1032-1048.

[12] Aprilice AB. (2013). *Products*. Available: http://www.nordensolar.se/en/products/.

[13] Vattenfall AB. (2013). *Producera din egen el med solceller*. Available: http://www.vattenfall.se/sv/solceller.htm.

[14] Fortum AB. (2013). *Vi erbjuder en helhetslösning på sol*. Available: http://www.fortum.com/countries/se/privat/energismart-hemma/sol/priser/pages/default.aspx.

[15] DinEl. (2013). *Prismall nyckelfärdig solcellsinstallation*. Available: http://dinel.se/privat/vara-elavtal/solceller1/priser/.

[16] Svensk Energi, "The electricity year and operations 2011," Svensk Energi, Stockholm, Swe., Sep. 2012.

[17] Nord Pool Spot AS. (2013). *Elspot prices*. Available: http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Hourly/.

[18] Svensk författningssamling 2012:971, "Förordning (2009:689) om statligt stöd till solceller." Stockholm, Sweden, 2012.

[19] Energimyndigheten. (2013). *Fördelning av medel 2013*. Available: http://www.energimyndigheten.se/sv/Hushall/Aktuella-bidrag-och-stod-du-kan-soka/Stod-till-solceller/Fordelning-av-medel/.

[20] R. Bohlin, Å. Ärlebrant, and R. Lundmark, "Beskattning av mikroproducerad el m.m.," Statens Offentliga Utredningar, Stockholm, Swe., Rep. SOU 2013:46, Jun. 2013.

[21] Svenska Kraftnät. (2013). *Medelpris för elcertifikat*. Available: http://certifikat.svk.se/Lists/PublicPages/StatisticsElCertificates.aspx.

[22] C.P.Cameron, W.E. Boyson, and D.M. Riley, "Comparison of PV system performance-model predictions with measured PV system performance," Photovoltaic Specialists Conf., San Diego, CA, 2008, pp. 1-6.