UPPSALA UNIVERSITET

UPTEC STS 22035
Examensarbete 30 hp
September 2022

Key Socioeconomic Factors for Domestic Solar Energy

An interdisciplinary analysis of the characteristics of photovoltaic and solar thermal installations in three Swedish municipalities

Sofia Ekbring

Civilingenjörsprogrammet i system i teknik och samhälle

UPPSALA
UNIVERSITET

Key Socioeconomic Factors for Domestic Solar Energy

Sofia Ekbring

Abstract

As a response to the increasing demand for renewable power, the solar photovoltaic (PV) market is growing fast. In addition to PV systems, the energy from solar radiation can be converted into heat energy in solar thermal (ST) systems. This study uses a method that identifies solar energy systems using aerial imagery and deep machine learning to create and evaluate an inventory of solar energy systems in three Swedish municipalities together with socioeconomic and demographic data, to understand the relation between different variables and PV and ST adoption. The variables are age, sex, birth region, education, unemployment, average income and economic standard. Information about the locations also include owner, time at residence, tax value, purpose of property and purpose of building. The relation is analyzed through a correlation and regression analysis at three different granularity levels: households, demographic statistical areas and municipalities.

Out of 692 inventoried PV systems and 399 ST systems, the majority was installed in rural or regional center areas. The most common buildings were residential and complementary. Most of the properties were owned by individuals, and the tax value of properties was in general lower for ST systems, indicating that it is more common for companies to install PV systems and at larger properties. The average income, age and percentage of males are higher for households that have adopted PV and/or ST systems compared to the municipalities average. However, the difference is clearer for PV systems than for ST systems.

The analysis concludes that share of the population in age group 45-64 years, share of males, share born in Sweden and high average income have a positive correlation to PV adoption. Share of the population within age group 25-44 years, unemployment and low economic standard is found to have a negative correlation to PV deployment. Positive correlation to ST adoption is found for a share of the population within age group 45-64 years and born in Sweden. Share of population in age group 24-44 years and unemployment was found to have a negative correlation to ST deployment.

Teknisk-naturvetenskapliga fakulteten

Uppsala universitet, Utgivningsort Uppsala

Handledare: Johan Lindahl Ämnesgranskare: Joakim Munkhammar

Examinator: Elísabet Andrésdóttir

Populärvetenskaplig sammanfattning

Den globala solcellsmarknaden växer snabbt som ett av svaren på den ökade efterfrågan på förnyelsebar energi runt om i världen. Solceller omvandlar energin i solens strålar till elektricitet, men energin i strålarna kan även användas till att värma upp luft och vatten genom solfångare, även kallat solvärme. Utvecklingen av teknikerna och den växande marknaden har ökat intresset för att förstå vilka som installerar olika solenergitekniker och vart dessa system installeras. Detta examensarbete har, i samarbete med Becquerel Sweden AB, genom ett program som använder sig av flygfoton och maskininlärning, inventerat solcells- och solvärmeanläggningar i tre kommunerna i Sverige.

Utifrån de identifierade platserna för varje anläggning har socioekonomisk (individers ekonomiska och sociala status) och demografiska data (befolkningen och dess sammansättning) använts för att analysera relationen mellan installation av solceller och/eller solvärme och flera variabler. De analyserade variablerna har varit ålder, kön, födelseregion, utbildning, arbetslöshet, medelinkomst och ekonomisk standard. För de identifierade systemen har även information om fastighetsägare, levnadstid i bostaden, syftet med byggnaden samt taxeringsvärdet på och syftet med fastigheten varit tillgängligt. Utöver en sammanställning har en korrelationsanalys (sambandsanalys) och en regressionsanalys (relationsanalys) utförts för att utvärdera förhållandet mellan installationsmängd och de analyserade variablerna. Analysen har genomförts på tre olika nivåer: hushållsnivå, SCB:s regionala indelning i demografiska statistikområden (DeSO) och kommunnivå.

Av de 692 inventerade solcellsanläggningarna och 399 inventerade solvärmeanläggningar, var majoriteten installerade på landsbygden eller inne i centralorter. De vanligaste byggnadstyperna för systemen var bostäder och komplementbyggnader. Störst andel av fastigheterna ägdes av privatpersoner, där andelen var större för solvärme än för solceller. Taxeringsvärdet på fastigheterna var generellt sett lägre för solvärmeanläggningar. Detta kan indikera att det är mer vanligt att företag installerar solceller än solvärme, och att de oftast gör detta på större och dyrare fastigheter. För hushållen med solenergianläggningar var medelinkomsten, åldern och andelen män högre än genomsnittet i varje aktuell kommun. Skillnaden mellan hushåll med anläggningar och utan var större för solceller än solvärme.

Resultat visar att en stor andel av populationen i åldersgrupp 45-64 år, stor andel män, stor andel födda i Sverige och en hög inkomst hade en positiv korrelation till installerad mängd solceller. En stor andel i åldersgrupp 25-44 år, stor andel arbetslösa och låg ekonomisk standard hade en negativ korrelation till solcellsutbyggnad. För solvärme fanns en positiv korrelation till en stor andel av populationen i åldersgrupp 45-64 år och stor andel födda i Sverige, samt en negativ korrelation till en stor andel i åldersgrupp 24-44 år och stor andel arbetslösa. Faktorer som kan påverka resultatet är ägarandelen av bostäder, vilka bostäder som är lämpliga för anläggningar och om bostäderna ligger på landsbygden. Det är viktigt att komma ihåg att korrelation inte nödvändigtvis betyder kausalitet (orsakssamband), men resultatet ger en insikt i hur olika socioekonomiska och demografiska variabler kan påverka vart och vilka som installerar solenergianläggningar.

Acknowledgements

This master thesis marks the end of my time at Uppsala University and the Master's Programme in Sociotechnical Systems Engineering.

This thesis has been carried out in collaboration with the company Becquerel Sweden AB and I wish to express my sincere gratitude to my supervisor Dr Johan Lindahl for all the knowledge and guidance along the way. You always helped me summarize my thoughts. I would also like to thank my subject reviewer, Associate Professor Joakim Munkhammar, for the support and help to manage this solid amount of data. Thank you!

At last, I want to thank my close ones for the support, coffee, and joy along the way.

Best regards,

Sofia Ekbring

Abbreviations and definitions

PV	Photovoltaic
ST	Solar thermal
BIPV	Building integrated photovoltaic
DSO	Distributed Systems Operators
DeSO	Demographic statistical areas
SEK	Swedish Krona
W_p	Peak power

Real property – The legal division of land

Property designation – The “name” of a real property

Table of contents

1. Introduction

The global photovoltaic (PV) market has grown unexpectedly fast the last couple of decades (Jaxa-Rozen and Trutnevyte, 2021) as a response on the increasing demand for renewable energy. The global power production from PV systems was about 997 TWh in 2020, which corresponds to about 4% of the electricity demand globally (Masson et al., 2021). PV systems convert the energy of the solar radiation into direct current electricity by the photovoltaic effect through solar cells (Naturskyddsföreningen, 2022) and are installed for a wide range of needs. From off-grid pico-PV-system of 0-10 W_p and solar home systems of 10-100 W_p to meet the electricity needs in rural off-grid areas for about 250 million people in 2019 (Lighting Global et al., 2020) to decentralized roof-mounted systems of varying size for self-consumption and export of excess electricity (Hunkin and Krell, 2020) and centralized electricity production through huge ground-mounted PV parks (Mu et al., 2021). PV systems in Sweden produced 0.9 TWh 2020, which corresponds to 0.5% of the electricity production in Sweden that year (Lindahl et al., 2020).

In addition to PV systems, the energy in the solar radiation can be used by conversion to heat through solar thermal (ST) applications. Heat corresponds to about 50% of the global final energy consumption, and 2020 was 407 TWh supplied by ST systems. The base in ST systems are solar collectors that use the energy in solar radiation and concentrate it into useful heat. ST systems can be used in both smaller and larger scale, in the range from roof mounted systems with the heat used domestically in the building to industrial applications and district heating (Weiss and Spörk-Dür, 2021).

The use and installation rate of PV and ST systems have increased worldwide due to their scalability, including lower absolute unit cost and investment risk, has made it possible to purchase, install and use PV or ST technologies for a large range of stakeholder (Wilson et al., 2020). About 40% of the PV market is distributed systems (single-family houses, multi-family houses, apartment buildings and public buildings) (Masson et al., 2021) and the corresponding number is 60% for ST systems (Weiss and Spörk-Dür, 2021). Currently, the global PV market is growing faster than the ST market (Masson et al., 2021).

The increasing number of systems and huge range of sizes make it difficult to track historical ST and PV deployment, which makes it important to develop new methods to assess installations volumes. One potential solution is to identify and record PV and ST systems after commission, for example by locating and measuring the size of the systems using remote aerial imagery and deep machine learning. A benefit with this type of approach is that it potentially can generate a database including number of PV and ST systems, size, and exact location of systems, including properties or buildings used for the systems. A database could potentially include off-grid PV systems and poorly inventoried ST systems (Mayer et al., 2020). Further, this information can thus be combined with socio-economic data in an attempt to try to understand which impact and relation different variables has on installed PV and ST systems.

This study addresses the issue of identifying small, decentralized grid connected PV systems, off-grid PV systems, and ST systems by aerial imagery and machine learning in Sweden. Sweden has a high share of stationary off-grid PV systems (Lindahl et al., 2021), small, decentralized PV system (Energimyndigheten, 2022a), and small-scale ST systems (Energimyndigheten, 2021). This study analyzes socioeconomic (involving both social and economic matters) and demographic (statistical characteristics of populations) data connected to the identified systems.

1.1 Purpose and research questions

The purpose of this thesis is to (1) create an inventory of solar energy systems and analyze their differences in terms of location, (2) identify and analyze socioeconomic and demographic variables that affects the adoption of solar energy systems and (3) identify and analyze differences between these variables for PV and ST systems. To fulfill the purpose, an inventory of available socioeconomic factors is to be performed. The following research questions are addressed in this thesis:

- Where are PV and ST systems installed in terms of buildings and type of areas, and are there any differences between the technologies?
- Are there any differences to be found between households with installed solar energy systems and those without, in terms age, sex and economic conditions?
- Do socioeconomic and demographic variables have an influence on or a relation to installed PV and ST systems?

1.2 Delimitations and limitations

This thesis is limited to investigate three chosen municipalities in Sweden: Falun, Knivsta and Uppvidinge. The project is delimited by latest available aerial images, taken in 2019 in Knivsta and 2020 in Falun and Uppvidinge. In addition, the analyzed socioeconomic and demographic variables are delimited to those available through Statistics Sweden and Lantmäteriet.

1.3 Disposition

This thesis is divided into six parts: Introduction, Background, Methodology, Data, Results, Discussion and Conclusions. The Introduction includes problem formulation, purpose and research questions. In the Background is the Swedish PV and ST market presented together with previous studies in the field. This thesis analyzes both PV and ST systems, and in the Methodology and Data are the procedure and data collection for both technologies presented jointly. The Methodology Section describes the inventory of solar energy systems, use and compilation of data, and the performed correlation and regression analysis. The Data Section includes more detailed information about data mentioned in the Methodology Section.

In both the Results and Discussion are PV and ST systems presented separately. The Results includes a presented compilation and the result of the correlation and regression analysis. In the Discussion are the presented results discussed and in the Conclusions are significant results summarized.

2. Background

In the following sections a brief overview of the PV and ST markets in Sweden is presented along with a review of previous research of PV and ST systems adopters and different socioeconomic and demographic factors' relation to PV and ST uptake. Figure Included are development of the different technologies and methodologies and identified result for different analyses of factors influence on PV and ST adoption.

2.1 Solar energy in Sweden

The solar energy market is in this thesis divided into two parts, solar photovoltaic (PV) and solar thermal (ST), which are presented in this section. The summary includes development (cumulative and annual), different types and investment aids.

2.1.1 The solar photovoltaic market

Historically, the PV market in Sweden did, almost exclusively, consist of a small, but stable, off-grid market. The majority of systems were installed at holiday cottages, marine applications and caravans. Installation of grid-connected PV systems in Sweden increased around 2006, and since 2007 more grid-connected PV capacity than off-grid capacity has been installed annually (Lindahl et al., 2021).

The introduction of the Swedish direct capital Subsidy programme for PV in 2009 contributed to a growing public interest (Palm and Tengvard, 2011). The purpose was to increase the annual electricity production from PV systems (and contribute to the transformation of the energy system) and a one-time state investment aid was available for installed PV systems (Riksdagsförvaltningen, 2021). The investment aid was replaced with a tax deduction for green energy in 2021 (Skatteverket, 2022a).

At the end of 2020 the total reported grid-connected PV capacity in Sweden was 1.089 MW. Out of this 1.016 MW was estimated to be distributed PV and 73 MW centralized PV. In addition, 17 MW off-grid PV applications were estimated to be in operation. This was a 57% increase of the total installed PV capacity compared to 2019. Total cumulative installed PV capacity in Sweden from 2010 to 2020 is presented in Figure 1 for off-grid, distributed and centralized PV (Lindahl et al., 2021). A significant increase can be observed for the last decade and the total installed capacity nearly tripled from 2018 to 2020.

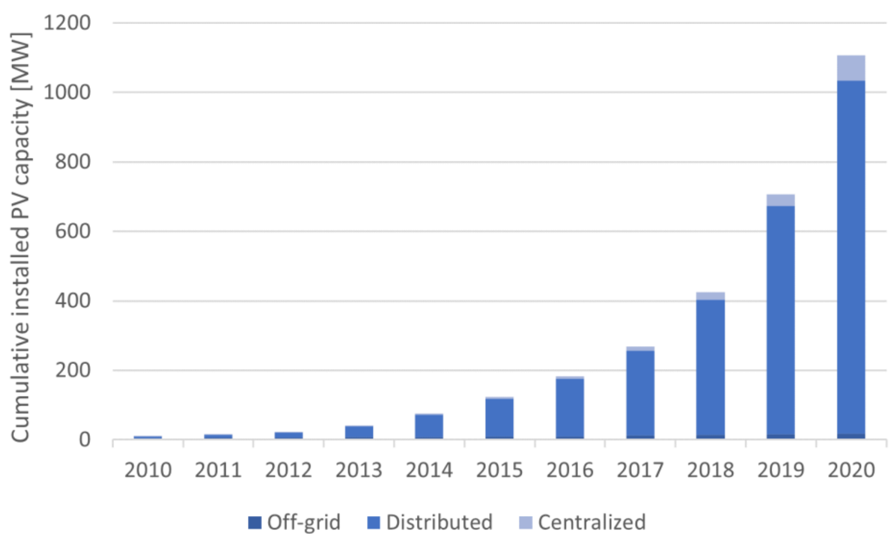

Figure 1: Total cumulative installed PV capacity in Sweden for 2010-2020 divided into off-grid PV, grid-connected distributed PV and grid-connected centralized PV.

The annual installed PV capacity from 2010 to 2020 is presented in Figure 2 to display the recent years' increase more clearly. The total installed capacity increased annually with around 80% between 2017 and 2019. Centralized PV reached over 100 MW installed annually 2018 and the installation rate has increased with around 100 MW per year since then. Around 1-2 MW off-grid systems have been installed annually in recent years.

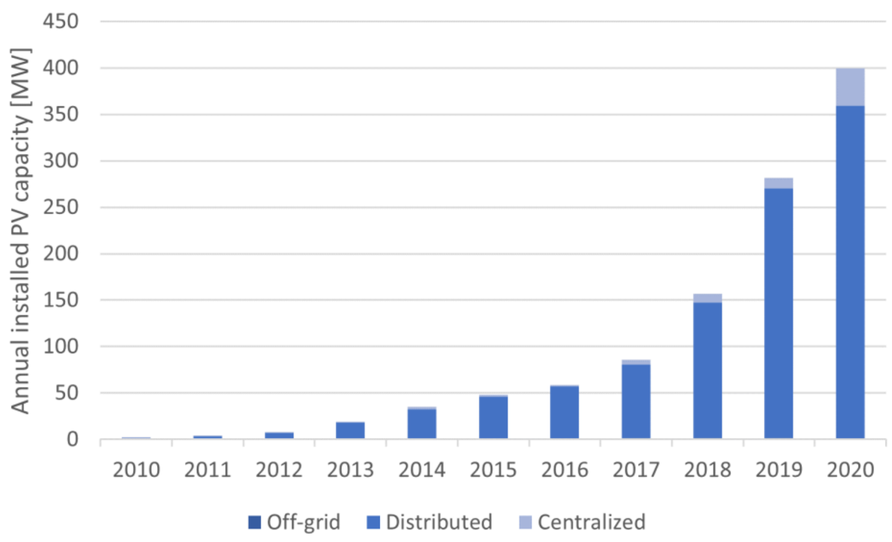

Figure 2: Total annual installed PV capacity in Sweden for 2010-2020 divided into off-grid PV, grid-connected distributed PV and grid-connected centralized PV.

2.1.2 The solar thermal market

The market for ST systems in Sweden has include five different technologies: (1) concentrating solar thermal collectors, (2) glazed flat-plate collectors, (3) evacuated tube collectors, (4) unglazed flat-plate collectors (Energimyndigheten, 2021) and (5) photovoltaic thermal hybrid solar collectors (PVT) (Bandaru et al., 2021).

An investment subsidy was available for private individuals and small-scale systems in Sweden between 2000 and 2011, and a majority of ST systems today were installed during this period. The investment grant was based on the ST system’s performance. In 2009, the grant was converted into an investment support, which was phased out in 2011. During the available period, 98% of the investment subsides were paid to single-family homeowners (Boverket, 2012).

The interest in ST systems has varied the last decades. Sales statistics for Sweden from 2000 to 2020 collected by Research Institutes of Sweden AB (RISE) are presented in Figure 3 in terms of total cumulative installed ST capacity (RISE, 2022). The most common technologies are flat-plate collectors and unglazed absorbers.

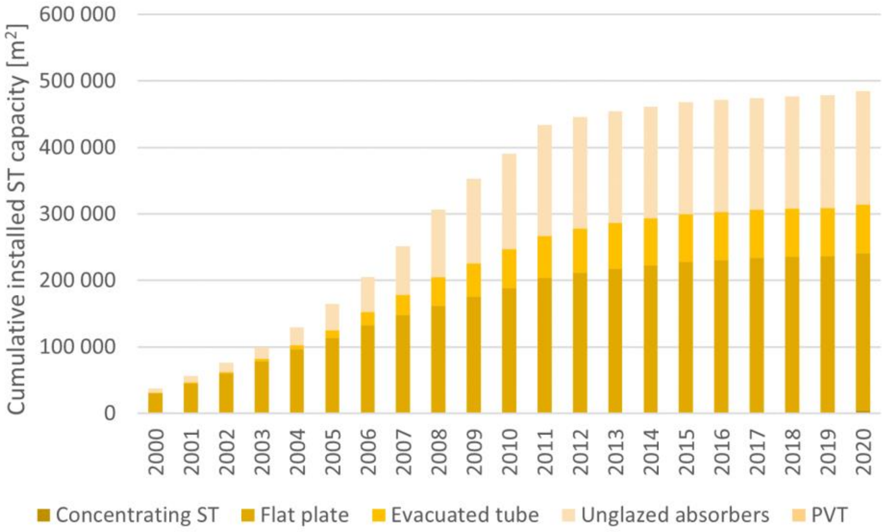

Figure 3: Total cumulative installed ST capacity in Sweden 2000-2020 divided into concentrating ST, flat plate, evacuated tube, unglazed absorbers, and PVT.

The ST market in Sweden has declined due to low profitability since the investment support was phased out, presented in Figure 4 in terms of annual installed ST capacity from 2000 to 2020 (Energimyndigheten, 2021). In addition, the introduction of the Swedish direct capital Subsidy program for PV in 2009 may indicate a political guidance for investments in solar energy systems. There is no direct support system for ST systems in Sweden today and the annual installation rate is small. A large number of the previous installed systems remain in use, but they are at the end of their technical lifetime.

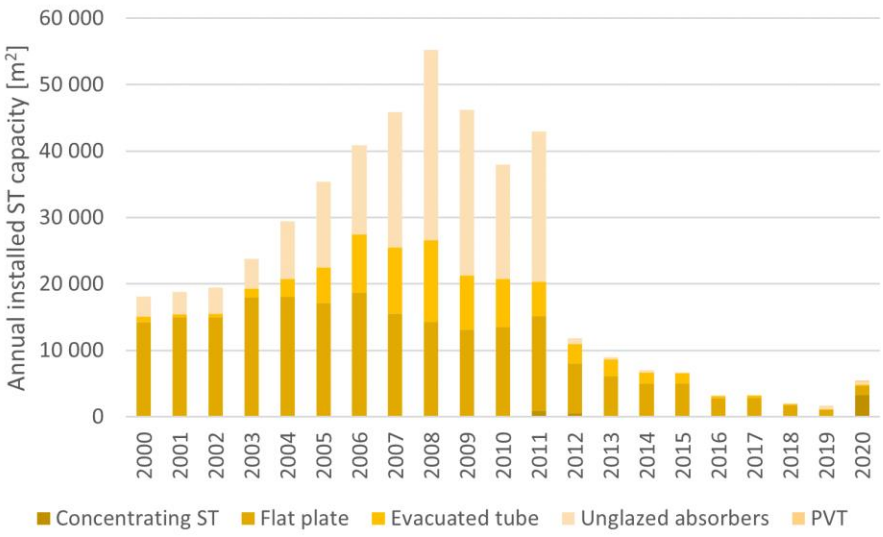

Figure 4: Total annual installed ST capacity in Sweden 2000-2020 divided into concentrating ST, flat plate, evacuated tube, PVT and unglazed absorbers.

2.2 Previous studies

In this section are previous research on adopters of PV and ST systems and socioeconomic and demographic factors, including methods and results, presented. There are a significantly higher number of studies analyzing factors influencing PV systems compared to ST systems, which reflects the content.

2.2.1 Motives of adoption of PV systems

As the market for PV systems grew in the early 2010s the interest in investigation of drivers and motives of adoption developed. Different approaches are possible and two of the most commonly used methods for studies of the area are (1) interviews with PV owners or important stakeholders and (2) analysis of the relationship between PV and different factors with focus on statistical significance, applied separately or combined.

The motives of adoption of solar PV in Sweden have been studied and presented in different ways and publications. In a qualitative study of the at the time very small Swedish PV market, Palm and Tengvard (2011) analyzed motives and barriers for early-adopter households. The result indicated that environmental concerns were the main motive of PV adoption at the time. In addition, financial and technological grounds as well as personal interest in self-sufficiency were also important factors that increased the probability of adoption. Financial barriers were one of the main reasons to not install PV (Palm and Tengvard, 2011).

The introduction of the investment aid for installation of PV in 2009 contributed to a growing public interest (Palm and Tengvard, 2011) and as the market grew, so did the number of systems and basis for analysis. In a study from 2016, which explored five municipalities in Sweden, with a high residential PV density in terms of number of systems per capita, Palm (2016) tried to identify local factors influencing the rate of diffusion of PV, through a survey and interviews with local actors. The study examined the still very early market in Sweden, and data from the investment subsidy scheme for grid-connected PV between 2009 and 2014 were used for the actual number of systems. Cluster effects and differences between municipalities located in rural or urban, costal or inland, northern or southern regions were analyzed. Important factors identified in the study were peer effects and local organizations or electric utilities promoting PV. However, factors such as high income and political orientation were ruled out as major explanatory factors explaining the high PV density in the studied municipalities (Palm, 2016).

Motives of adoption may, however, change over time. In a study published later, Palm (2020) investigated motives of adopting residential PV based on the hypothesis that early adopters are known to partly be driven by other motives than late adopters. By a systematic literature review and an empirical investigation of Swedish adopters over a nine year period the author found that early adopters of PV are more driven by non-financial motives such as environmental concern and techno philia while later adopters are predominantly driven by economic gain (Palm, 2020).

2.2.2 Adopters of PV and: socioeconomic and demographic factors

While the Swedish market still was in an early phase, there were other markets where the diffusion was more advanced. In addition to investigation of motives for adoption, interest in similarities between adopters have been raised. In a study of the more advanced distributed PV market in California, Bollinger and Gillingham (2012) used the number of PV systems together with demographic and socioeconomic data on zip code-level to examine the determinants of adoption by an ordinary least square estimation. The result showed that a higher adoption rate was associated with factors such as households with a hybrid vehicle, share of the population being male, share of the population being white and households with home repairs. Lower adoption rates were associated with the total population within the zip code, share of population aged 20-45, share of population over 65 and high home values. There was also shown that households with a lower income are less likely to adopt PV but more likely to be influenced by peer effects (Bollinger and Gillingham, 2012).

In a study of Connecticut on block group level, much smaller than zip codes, Graziano and Gillingham (2015) showed that the block level housing density and share of renters decreases adoption. Other investigated socioeconomic factors show less statistically significant results. There is for example weak evidence that higher median household income or a larger share of the population being white increases adoption. Results for political affiliation variables and unemployment rate were not statistically significant (Graziano and Gillingham, 2015).

In a study of Flanders, Belgium from 2016, De Groote et al. tried to explain the heterogeneity in PV adoption rates. Flanders' PV adoption level was high during 2006-2012 due to active government intervention. The results show a strong connection between income and PV adoption and that wealthier households are more likely to adopt, because, among other things, they are more frequent house owners or owners of houses that are better suited for PV (De Groote et al., 2016)

De Groote et al. (2016) analyzed PV systems in very disaggregated local areas, statistical sectors, typically only a set of streets, with an average of 280 households per sector. Number of households controlled for the fact that statistical sectors are not of equal population size and the number of PVs were expected to rise proportionally to the number of households. The main dependent variable was the number of PV systems per statistical sector. The main findings of the study concern the role of housing characteristics, which has not been considered in previous studies. PV adoption is more likely in larger and more recently built houses, and of younger households because they live in more recently built houses. Education did not seem to play a significant role and it is shown that income, household age and house value is less important than previously. Housing characteristics and household size show a significant role. Other analyzed variables were for example population density, number of households, household ownership, gender, employment (De Groote et al., 2016).

In a study published in 2018, Bernards et al. tries to quantify the effect of different factors on adoption of grid-connected residential energy technologies in the Netherlands. The results show that factors that have a positive correlation with PV systems is the logarithm of the average monthly income, number of PV systems in a 100 m radius prior to own system, the home ownership rate, percentages of two-parent households, percentage of household members within the age group 0-14 and the total number of residents. Negative correlation is shown for factors such as number of PV systems in a 250 m radius prior to own system, percentages of one-parent households, house price, income, percentage of household members within the age group 25-44, percentage of household members within the age group 75+, address density and number of households in the zip code (Bernards, Morren and Slootweg, 2018).

In a publication from 2019, Lukanov and Krieger analyze the cumulative and annualized rates of PV adoption across California, investigating whether the transition is occurring equitably across the state's various demographic and socioeconomic groups. The aim is to provide a comprehensive assessment of the role played by demographic and socioeconomic factors, among others, in this context. The result shows persistently lower levels of PV adoption in disadvantaged communities and the analysis reveals positive correlation between PV uptake and median household income, negative correlation for education, housing burden, linguistic isolation, poverty and weak negative correlation for unemployment (Lukanov and Krieger, 2019).

Lukanov and Krieger (2019) used both a regression and a correlational analysis to correlate solar deployment with socioeconomic and demographic factors on the census tract level. Addresses for individual PV systems were not publicly available, instead, the total number and capacity of PV systems within each census tract code was used. Indicators available on census tract level were educational attainment, housing burden, poverty and unemployment. In addition, the 5-year-average (2012-2016) median household income for each census tract was obtained through data from large-sample surveys. The customer segment (residential, commercial, government, nonprofit, school, non-residential) of the systems was also available. The authors performed an ordinary least square (OLS) multiple regression model for solar adoption and evaluated Spearman's rank correlation coefficient between residential PV adoption and the variables. Urban and rural PV adoptions rates were compared but no significant trends of solar adoptions based on population density was found (Lukanov and Krieger, 2019).

Balta-Ozkan et al. (2021) summarizes previously performed studies with varying resolution and group analyzed variables into five categories: household and built environment characteristics, economic and physical factors, environmental attitudes and peer effects. The summary show that, for example, higher education, smaller families, the percentage of male and white population, low population density, high house density, high ratio of dwellings that have their own roof space to the total households, larger houses, high ratio detached houses, high income, high accumulated capital, high share of home ownership and high number of preexisting systems have a positive influence on PV adoption (Balta-Ozkan et al., 2021).

In addition, Balta-Ozkan et al. (2021) analyzes spatial patterns of PV adoption in the UK. The authors discuss different drivers of adoption at the local level and emphasize that it is unlikely that effects of different factors on PV adoption are spatially or temporally uniform. Therefore, it is of importance to understand the spatial heterogeneity of socio-economic factors driving PV adoption patterns. In the study, the authors used both a global ordinary least square (OLS) regression model and a geographically weighted regression (GWR) model. A global OLS model does not cpnsider local variations while a GWR model generates a set of local regression models with local parameter values for each region in the data set. In the study, the GWR model, which considers a spatially varying relationship between socioeconomic variables and PV adoption, reveals significantly more variability than the OLS regression model (Balta-Ozkan et al., 2021).

The result of the OLS model revealed that median income and population density had a negative influence on local adoption of PV and that education level, share of detached houses, share of self-employed people and number of charities had a positive influence. In comparison to the GWR model, the GWR model was a statistically significant improvement. For the GWR model, the result was in most cases similar to the OLS models', but with variations. For example, population density and education had bidirectional impact on PV adoption. In summary, the result showed that location within the UK matters in an evaluation of different variables influence on PV adoption (Balta-Ozkan et al., 2021).

2.2.3 Adopters of ST and socioeconomic factors

There are, compared to the PV market, very few studies analyzing the ST market in terms of adopters, similarities, and socioeconomic factors. The ST market in Sweden has declined since the investment support was out phased, which are also shown for unsubsidized ST in other European countries at the time (Louvet et al., 2019), and it is difficult to inventory the number of systems, due to its characteristics. As a result, the basis of analysis is smaller for ST systems compared to PV systems. However, there is still some previous research analyzing possible similarities between adopters.

In a study from 2009, Mills and Schleich tried to assess the effects of geographic, residence, and household characteristics on the adoption of solar thermal technologies by an empirical analysis of data from German households. The adoption level of solar thermal was still low in the EU and the study was the first large-sample study analyzing the impact of a broad set of geographic, residential, and household characteristics on the diffusion of solar thermal technologies (Mills and Schleich, 2009).

Mills and Schleich (2009) used a quantitative framework to estimate determinants of adoption of solar thermal technology compared to non-adoption. The data used was based on a survey from 2002. Example of factors analyzed in the study that were assumed to be associated with solar thermal adoption are higher solar radiation levels, population density, age of residence, type of residence, type of heating system, renter or owner of the building, size of the household, age of the household, education, hot water and space heating demand, environmentally friendly attitudes, and income. The results show that there is little evidence of differential adoption by distinct socio-economic groups (Mills and Schleich, 2009).

In another study from 2011, Woersdorfer and Kaus analyzed the, at the time, very low solar thermal diffusion in Germany and decisive demand side factors. The data used was based on a consumer survey in northwestern Germany in 2007. Factors investigated were for example positive environmental attitude, knowledge of the technology and the presence of solar thermal systems among peer consumers. The results did not indicate a strong increase in diffusion within the following few years. Important determinants of prospective adoption were however environmental attitude, knowledge, and household income. The only variable that seemed to function as a trigger for the diffusion of the solar thermal technology was peer group behavior (Woersdorfer and Kaus, 2011).

3. Methodology

The aim of this thesis is to analyze different socioeconomic and demographic factors' relation to and impact on solar energy systems in Sweden. To perform this study, a complete inventory of 692 PV and 399 ST systems in three different municipalities in Sweden was created by a method that used machine learning and aerial imagery. The created database of solar energy systems was complemented through geodata services offered by Swedish agencies with socioeconomic factors on both a solar energy system ownership level and with demographic statistics on district level within the municipalities. Based on available aerial imageries and socioeconomic data the year of analysis is 2020 (2020-12-31), which applies to all contexts presented in this section. To evaluate the relation to and impact of the different variables, a compilation of the result along with a correlation and regression analysis was performed. This section presents the methodology, data management and assumptions made in this thesis and an illustrated overview is presented in Figure 5.

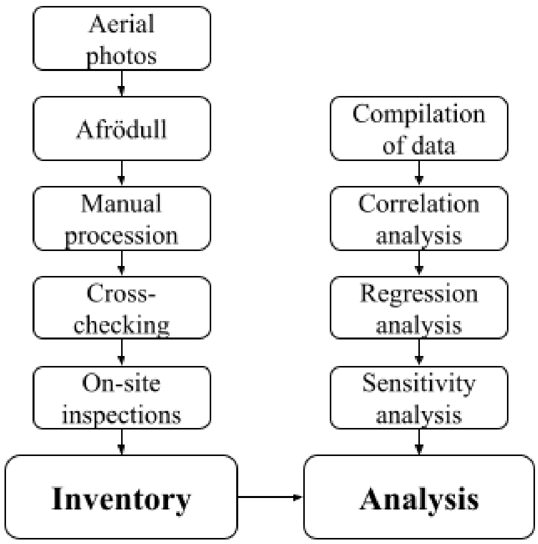

Figure 5: An illustrated overview of the methodology including inventory of solar energy installation and analysis of the result.

3.1 Inventory of solar energy systems

To enable the analysis of solar energy systems in this thesis, it was necessary to compile a complete inventory of the number and size of different solar energy systems, as well as their locations. This section covers the execution of the inventory of solar energy systems and the choice of the geographical areas of investigation.

Due to the scope of this thesis, the geographical area of investigation needed to be limited to keep a high granularity, which Lukanov and Krieger (2019) emphasized, usually is preferred. Municipalities were chosen as areas due to their clear boundaries and the availability of data at different aggregations levels.

3.1.1 Choice of municipalities

Three out of Sweden's 290 municipalities (Regeringskansliet, 2015) were chosen to be analyzed: Falun, Knivsta and Uppvidinge. In two of the municipalities, Falun and Knivsta, the inventory of solar energy systems was completed by Becquerel Sweden AB before the start of this project. This enabled a third municipality, Uppvidinge, to be included and analyzed within the scope of this thesis. In the choice of municipalities, size and type as well as location was varied on purpose as varying characteristics of the investigated municipalities enabled analysis of additional aspects. This was motivated by the fact that similar comparison has been performed by Palm (2016) and Lukanov and Krieger (2019) with variated results, and it was therefore of interest to analyze further. Key numbers about the municipalities are listed in Table 1.

Table 1: Summarized key figures in 2020 for the analyzed municipalities Falun, Knivsta and Uppvidinge provided by the municipalities and Statistics Sweden.

	Area [km^3]	Population [inhabitants]	Average age [years]	Average income [SEK]	Employment [%]
Falun	2 000	59 500	42.4	29 000	82.6
Knivsta	300	19 100	36.9	35 400	87.2
Uppvidinge	1 200	9 500	43.5	25 600	81.6

Falu municipality is located in central Sweden in the southeastern part of the province Dalarna. The area of the municipality is 2 000 km^2 (Falu kommun, 2021) and the municipality had 59 500 inhabitants in 2020 (Statistics Sweden, 2022e). In addition to the regional center Falun, there are eight urban areas, such as Bjursås, Grycksbo, Svärdsjö and Sundborn. The average age in the municipality is 42.4 years (Statistics Sweden, 2022b) and a majority of the population, 87.3%, live in the urban areas of the municipality. The average income was 29 000 in 2020 and 82.6% of the inhabitants between 20 and 64 years were employed (Statistics Sweden, 2022e).

Knivsta municipality is located north of Stockholm, close to Uppsala. The area of the municipality is 300 km^2 and the regional center is Knivsta (Wikipedia, 2022). It had 19 100 inhabitants in 2020 (Statistics Sweden, 2022e) with an average age of 36.9 years, one of the lowest in the country (Statistics Sweden, 2022b). There are two urban areas, Knivsta and Alsike, (Knivsta kommun, 2021) where 72.8% of the population lives (Statistics Sweden, 2022e). The average income was 35 400 in 2020 and 87.2% of the inhabitants between 20 and 64 years were employed (Statistics Sweden, 2022e).

Uppvidinge municipality is located in the province Småland in southern Sweden. The municipality's area is 1 200 km^2 (Uppvidinge kommun, 2022) and the size of the population was 9 500 in 2020 (Statistics Sweden, 2022e). The largest urban area and regional center is Åseda, other urban areas are for example Lenhovda, Norrhult-

Klavreström and Alstermo. The average age is 43.5 years (Statistics Sweden, 2022b) and 74.3% of the population live in the urban areas. The average income was 25 600 in 2020 and 81.6% of the inhabitants between 20 and 64 years were employed (Statistics Sweden, 2022e).

The three chosen municipalities were thus of different sizes and types. Falun is a large municipality with a relatively average population density. Around 70% of the population lives in the regional center and those remaining are evenly distributed between other urban and rural areas (Statistics Sweden, 2022d). Knivsta is a much smaller municipality with a population density twice that of Falun. Over 70% of the population lives in the regional center and the remaining in rural areas (Statistics Sweden, 2022d). Many of the inhabitants in Knivsta commute to the large and close cities of either Stockholm or Uppsala. Uppvidinge is a municipality of a relative average size with a low population density, around a quarter of that of Falun. The population is almost evenly distributed between the regional center, other urban and rural areas but with a slightly larger proportion in rural areas (Statistics Sweden, 2022d).

To summarize, the municipality of Falun represented a large urban/rural municipality centered around the regional center, the Falun city. Knivsta represented a suburban municipality and Uppvidinge a rural municipality. The different characteristics of the chosen municipalities contributed to a broader perspective of the analysis and enabled a comparison of different types of municipalities in terms of solar energy systems. However, the municipality's differences regarding for example average income, population density and distribution between urban and rural areas required awareness and consideration in a comparative analysis.

3.1.2 Identification of solar energy systems

In this thesis, a machine learning tool which used aerial imagery to identify solar energy systems was available through Becquerel Sweden AB. The tool, which will be referred to as Afrödull, was still in the development phase but aimed to be able to easily identify all solar energy systems using aerial imagery. As a result of the current development status, Afrödull returned a large number of suggestions of solar energy systems when applied to a geographical area.

The suggested systems were visualized using geographic information systems (GIS) software. GIS is a computer-based system that links digital maps to information about existing things at a specific geographical location (Lantmäteriet, 2022c). Through the visualization, the result was processed and incorrectly identified systems could be excluded and missing systems added. The manual correction of the result from Afrödull was in the case of PV systems helped by a cross-check with the local Distributed Systems Operators (DSO) register over grid-connected PV systems (further explained in Section 0) and the database of the Swedish direct capital subsidy programme (called SVANEN), further explained in Section 4.1.2. These two databases contain information about which properties that contain PV systems but lack information about the exact coordinates. Hence, the cross-check with these two databases was used as an indicator if suggested location of a PV system were correct or not.

In some rare cases, the visualization through GIS software was not enough to manually ensure existing solar energy systems. For these systems physical on-site inspections were necessary to complete the set. The on-site inspections also clarified uncertainties regarding type of solar energy system, design and/or location. The boundaries of the systems were, after identification, manually marked and saved as a polygon object using GIS software. Through the polygon object and the GIS software, each solar energy system was given coordinates, and from the polygon a spatial area spread. On-site inspections also enabled adding a few systems not identified by Afrödull to the inventory. Examples of identified ST and PV systems and created polygon objects are illustrated in Figure 6a and 6b, respectively.

Figure 6a: Afrödullô suggested area with a PV system (green square) and identified PV system (blue polygon).

Figure 6b: Afrödullô suggested areas with a ST system (green square) and identified ST system (orange polygon).

Through the described procedure, a complete set of all PV and ST systems was compiled for three municipalities. The set included the measured area and type of system as well as coordinates. Through the coordinates and area spread, all systems in the three municipalities could be connected to the property designation of the real property and the type of building of the system through available geodata services and products, explained further in Section 3.2. Some solar energy systems were installed on the ground and therefore not connected to a type of building, and instead automatically classified as ground-mounted in the data set.

There are several benefits to the approach in this thesis compared to only using either the register of DSO’s grid-connected PV systems or the SVANEN database (as in the study from 2016 conducted by Palm). Firstly, a complete inventory of PV systems that include systems installed without solar support (in the case of SVANEN) and off-grid (in the case of both and local DSO registers and SVANEN) was created. The drawback is that PV systems had to be visible from the sky and have clear physical characteristics to be identified by Afrödull. This means that vertical or high-tilted systems and BIPV systems was not identified. In addition, it was also more difficult to detect smaller solar energy systems. To a large extent, it was possible to reduce this impact by the cross-check with the Swedish direct capital Subsidy programme and local DSO, and both vertical and BIPV systems that these two databases had information about was manually added to the inventory.

Secondly, this method means that the inventory also includes ST systems, which is not registered in any database in Sweden. Thirdly, as compared to local DSO registers or SVANEN, the method used gives the exact geographical location of the PV and ST systems, while the two existing databases only have information about the location on the level of "somewhere within a real property". Through the coordinates assigned to the PV and ST polygons the property designation of the real property (the legal division of land) and the exact building they are installed on can be linked.

3.2 Linking socioeconomic and demographic data

Property designation and coordinates of each solar energy system were used as keys to retrieve information about the owner and the neighborhood within a demographic statistical area through available geodata services and products. In this section, different levels of aggregation and an overview of available socioeconomic and demographic data are presented. In Section 0 and 4.3, all data from the different sources is presented in detail.

3.2.1 Levels of aggregation

Previous research has identified systems through different approaches and analyzed data at different levels and granularity, from households and statistical sectors (De Groote et al., 2016), block group (Graziano and Gillingham, 2015), census tract (Lukanov and Krieger, 2019) and zip codes (Bollinger and Gillingham, 2012; Bernards et al, 2018) to municipalities (Palm, 2016). Through the retrieved property designation and coordinates of each system, the highest granularity available in this thesis was household level, i.e., real property (the legal division of land), the exact building for each system and the household living on the address.

In addition to household level, socioeconomic and demographic data were available at two, more aggregated levels. The most aggregated level was the municipality level. Each municipality is divided by Statistics Sweden into several fixed demographic statistical areas (DeSO). The size of the DeSOs is determined based on population and building concentration and the areas can therefore have a very varying spatial size. The size of each DeSO's population is between 600 and 3.500 inhabitants but the majority have a population of around 1.500 inhabitants (Statistics Sweden, 2022c). Through property designation and coordinates, each PV and ST system or household could be linked to a DeSO.

There are three different categories of DeSOs: one (A) for areas mainly located outside larger population concentrations or urban areas, i.e. rural areas, one (B) for areas mainly located in a population concentration or urban area but not in the municipality's regional center (urban areas) and one (C) for areas mainly located in the municipality's regional center (Statistics Sweden, 2022c). The total number of DeSOs and distribution between the different categories is displayed in Table 2 for the chosen municipalities Falun, Knivsta and Uppvidinge.

Table 2: Total number of DeSOs and distribution between the different types: rural area (A), urban area (B) and regional center (C) for the analyzed municipalities Falun, Knivsta and Uppvidinge.

Municipality	Total number of DeSOs	Mainly rural area (A)	Mainly urban area (B)	Mainly regional center (C)
Falun	37	6	5	26
Knivsta	10	3	0	7
Uppvidinge	6	2	2	2

To summarize, this thesis includes three different levels of aggregation: household, DeSO and municipality.

3.2.2 Available data and chosen factors

Through the property designation and Statistics Sweden, Lantmäteriet and Ratsit, information about the owner, household, general and detailed purpose of the property and the property's area and tax value was available, explained further in Section 0 and 4.3. Each building has a specific building code, which makes information about the general and detailed purpose of the building available. In addition, demographic statistics on DeSO and municipality level were retrieved from Statistics Sweden.

Factors that were possible to extract from the Swedish authorities and services are total population, number of households, age, sex, birth region, education, unemployment, average income, economic standard (disposable income per consumption unit), property purpose, property owner, property size, tax value of property and building purpose. The chosen variables to analyze are displayed in Table 3 together with a short explanation, available granularity levels and source of the data. The data is further explained in Section 0 and 4.3.

Table 3: Overview of chosen socioeconomic factors, including detailed information, available granularity level and source of data.

		Granularity			
	Details	Municipality	DeSO	Household	Source
Population	Total number of households	X	X	-	Statistics Sweden
	For all of age >20	-	-	X	Ratsit
Age	7 age groups	X	X	-	Statistics Sweden
	For all of age >20	-	-	X	Ratsit
Sex	Total distribution	X	X	-	Statistics Sweden
	For all of age >20	-	-	X	Ratsit
Birth region	Sweden, Europe, the rest of the world	X	X	-	Statistics Sweden
Education	Age 25-64	X	X	-	Statistics Sweden
Unemployment	Age 20-64	X	X	-	Statistics Sweden
Average income	Age >20	X	X	-	Statistics Sweden
	Age >20	-	-	X	Ratsit
Economic standard	4 groups, age >20	X	X	-	Statistics Sweden
Property purpose	General and detailed	-	-	X	Lantmäteriet
Property owner	Taxed owner and legal registration	-	-	X	Lantmäteriet
Tax value	Buildings, land and total	-	-	X	Lantmäteriet

To clearer illustrate the extracted data, different sources of data and aggregation levels, an illustrated overview is presented in Figure 7.

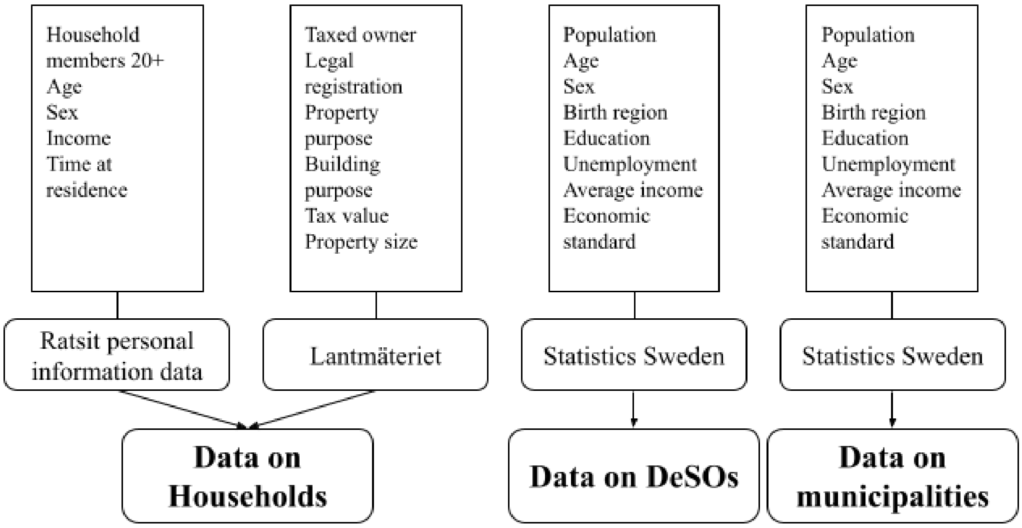

Figure 7: An illustrated overview of available data and chosen variables, sources of data and granularity levels.

3.3 Compilation of data

The compilation of the inventoried solar energy systems is presented in this section. Included are the execution of an overview of identified systems and households related to each system in a private residential data set.

3.3.1 Inventoried solar energy systems

The inventory of solar energy systems consists of PV and ST systems and information regarding location, the real property, type of building and household connected to each system. To know and understand the data set of inventoried systems, a compilation of the systems physical characteristics was performed. Firstly, an overview of the types of inventoried systems was created. In total were 736 systems identified in Falun, 200 in Knivsta and 155 in Uppvidinge. The data set was then divided into PV and ST systems. For the data set of each type of systems, a compilation of type of DeSOs, property and building of all installed systems was performed.

The compilation of information regarding the households connected to inventoried solar energy systems is presented in the following section.

3.3.2 Private residential systems

The original data set of all solar energy systems on all real properties in the chosen municipalities contained all completed systems at the time of the aerial photos. To enable an analysis of residential solar PV and ST, it was necessary to modify the data set. With information available through Lantmäteriet, the type of owner of each property was known. Based on this, all solar energy systems on properties owned by companies were assumed not to have been performed by individuals and were therefore removed from the private residential data set. The systems were either of type solar PV, solar ST, vertical PV or BIPV and to analyze them separately the data inventory was divided into two sets: PV (including vertical PV and BIPV) and ST.

Each real property's legal registration holds information about the registration date of the current owner, and through Ratsit information about the latest change of address for the owner was available. Based on this information, solar energy systems, for which the owner acquired the property after the aerial photos were taken, were removed from the set, as there was no information about previous owners available. By this, data of owners known to not be responsible for the actual acquiring of a solar energy system were omitted from the analysis. For the set containing PV systems, date of commission of the installation were available from the local DSO register and/or the Swedish direct capital subsidy database (if the owner applied for the subsidy). However, for off grid systems, which are not included in neither of these databases, no information about date of commission exists. For systems not covered in the Swedish direct capital Subsidy programme's database, the current owner was assumed to be the one responsible for the system. This holds for all types of systems, including ST.

The legal registration of a real property can be held by one or more individuals. The most common is one individual holding the legal registration or a married couple sharing it. To be able to compare data on property level with data on municipality and DeSO level, there was a need for consistency. Hence, information about the owning household of each real property was used as a variable instead of the specific owner of each real property. More specifically, all individuals living on the same address as the legal owner, information available through Ratsit, was considered as a part of the owning household. However, due to the format of available data on municipality and DeSO levels, as well as lack of data, only individuals over age 20 could be accounted for as members of the household. Just as for real property owners, individuals registered at the address after the systems were commissioned or the aerial photos were taken were omitted from the households. In addition, individuals for which information were not available through Ratsit were removed from the household. This applied when the legal owner was one individual or more living on the same address. However, if the household lived outside of the chosen municipality, the solar energy system was removed from the residential data set, as the gathered data only cover the chosen municipalities.

If there were more than one owner, not living at the same address, special conditions applied. If one of the owners lived at the real property of the solar energy system, the chosen household was the one at the property. The other owner or owners were disregarded. If one of the owners lives in the municipality and the others don't, the chosen household was the one at the address of the owner living in the municipality. If there were more than one owner, all living in the municipality but not at the real property of the system, the system was removed from the residential data set due to definition difficulties regarding the household.

The omitted solar energy systems mentioned above is motivated by non-existing or uncertain background data, as can be motivated since it only applies for few cases, and therefore only has a small effect on the total residential data set. There were 37 systems omitted in Falun, 8 in Knivsta and 19 in Uppvidinge as a result of the owning household living outside the municipality or acquired the real property after 2020-12-31. In addition, 12 systems were omitted in Falun due to lack of data or definition difficulties. As a result, 566 systems in Falun, 152 in Knivsta and 96 in Uppvidinge were included in the total private residential data set.

It should be noted that, just as for previous owners of real properties, there was no information available for individuals not living at the address of the legal owner at the time for data collection (February to May 2022). This means that individuals that lived at the address at the time for installation of a system, but not during the data collection, were not included in the household. Also, the private residential data set focus primarily on year-round residences, but since focus is at the owner of each real property and their address, some cottages might be included. However, this was somewhat regulated by removing households which lived outside the municipality.

3.4 Correlation and regression analysis

Correlation and regression analysis can be used to determine different socioeconomic and demographic factors' relation to, and impact on, installed private residential PV and ST density. Bollinger and Gillingham (2012) used an ordinary least square estimation and Lukanov and Krieger (2019) used both an ordinary least square multiple regression model for solar adoption and evaluated Spearman's rank correlation. In addition, Lukanov and Krieger concluded that a correlation analysis can provide information about different variables' relative influence on solar adoption rates and that regression analysis allows control for confounding effects between independent variables (Lukanov and Krieger, 2019). This section describes the approach of this thesis correlation and regression analyze and the chosen dependent and independent variables, which will be used in both the correlation and regression analysis. In addition, a sensitivity analysis of the result is presented.

3.4.1 Choice of dependent and independent variables

To evaluate different socioeconomic and demographic factors' relation to and impact on solar energy systems deployment, the dependent variable is chosen to represent PV and ST density. De Groote et al. (2016) used number of PV system per statistical sector as dependent variable, Lukanov and Krieger (2019) used PV adoption in kW/capita and Balta-Ozkan et al. (2021) used the natural logarithm of the number of PV systems under 10 kW.

Since data of solar energy systems used in this thesis were available in quantity and not installed capacity in case of PV, the dependent variable representing PV and ST will be expressed in number of systems and kW_p for PV systems. In addition, as this thesis has detailed information on which building each solar energy system is installed on and who lives in these buildings, the density is measured in #/households instead of #/capita, as it is believed this give a higher accuracy. The chosen dependent variable is in line with variables used in previous studies.

Variables that have been analyzed by previous research regarding influence on PV adoption are for example *age* (Bollinger and Gillingham, 2012; De Groote et al., 2016; Bernards et al., 2018; Lukanov and Krieger, 2019), *sex* (Bollinger and Gillingham, 2012; De Groote et al., 2016; Balta-Ozkan et al., 2021), *percent of population being white* (Bollinger and Gillingham, 2012; Graziano and Gillingham, 2015; Balta-Ozkan et al., 2021;), *ethnicity* (Lukanov and Krieger, 2019), *family size* and *education* (De Groote et al., 2016; Lukanov and Krieger, 2019; Balta-Ozkan et al., 2021), *unemployment* (Graziano and Gillingham, 2015; De Groote et al., 2016; Lukanov and Krieger, 2019), *income* (Graziano and Gillingham, 2015; De Groote et al., 2016; Bernards et al., 2018; Lukanov and Krieger, 2019; Balta-Ozkan et al., 2021), *share of home owners* (Graziano and Gillingham, 2015; De Groote et al., 2016; Bernards et al., 2018; Lukanov and Krieger, 2019; Balta-Ozkan et al., 2021), *home values* and *total population* (Bollinger and Gillingham, 2012; De Groote et al., 2016; Bernards et al., 2018). The analyzes have used different methods and showed varied result for the investigated variables, with different levels of influence and directions. There is little evidence of differential ST adoption by distinct socioeconomic groups (Mills and Schleich, 2009; Woersdorfer and Kaus, 2011). Based on this, it is still of interest to further analyze these variables for both PV and ST systems.

The analyzed independent variables in this thesis are thus chosen based on previous research and available data and presented as follows. Age is represented through five independent variables corresponding to percentage of the population in different age groups. The variables are age group *0-15 years*, age group *16-24 years*, age group *25-44 years*, age group *45-64 years*, and age group *>65 years*.

The independent variable representing the distribution between the sexes is called *Sex* and expressed as the percentual share of males. The choice male as a base is motivated by the fact that there is a slightly higher percentual share of men in the Swedish population (Statistics Sweden, 2022e). As a result, a value over 50% corresponds to a higher number of men while a number below 50% corresponds to a higher number of women.

Birth region as an independent variable is referred to as *BReg* and represents the percent of the population for whose birth region is Sweden. A high number corresponds to a high percentage of the population born in Sweden while a low number corresponds to a high percentage born outside Sweden, i.e., Europe or the rest of the world, including data missing. The choice is made taking into account the fact that persons for whom data is missing are included in the group representing birth regions outside Europe.

The independent variable representing education level is called *Educ* and represents the percentage of the population with a post high school education, including both less than three years and more than three years of higher education along with doctoral studies. The percentage is calculated out of the total number of persons, minus those for whom data is missing. A high percentage corresponds to a higher amount of the population with a higher education and a low percentage corresponds to a lower amount of the population with a higher education. This is in line with Lukanov and Krieger (2019) who representing the education variable as percent of the population over age 25 with less than a high school education, i.e. lower education (Lukanov and Krieger, 2019).

Unemployment is represented through the independent variable *UEm* and expressed as the percentage of the population being unemployed, with a low percentage corresponding to a high employment rate.

Economic conditions are represented in several ways. The first economic independent variable is average income, referred to as *AInc*, which corresponds to the average income of households within the area. A higher average income indicates possible better economic conditions. The second economic independent variable is the average economic standard, *EcSt*. This variable takes different types of household compositions into account, which might be a more equitable representation than AInc. Both variables are included in the analysis.

Economic standards are also represented through four groups: Low, MLow, MHigh and High. Two additional independent variables representing low income, *LInc*, and high income, *HInc* are included. *LInc* corresponds to the percentage of households within the group Low while *HInc* corresponds to the percentage of households within the group High.

3.4.2 Correlation analysis

The correlation between all variables, including dependent variables and independent variables, was examined through Pearson's correlation coefficient, defined in Equation 1, and a correlation matrix. Pearson's correlation coefficient provides an insight into the linear relationship between two factors and whether they covariate or not. The correlation (r) between two variables (x and y) are calculated through the values and average value ($\bar{x}$ and $\bar{y}$) of each variable. The calculated correlation coefficient is a value between -1 and 1, the correlation can thus be either negative or positive.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \qquad (1)$$

A negative linear correlation indicates that when one factor increases, the other decreases, and vice versa. A positive linear correlation indicates that when factor one increases or decreases, so does the other factor. A correlation coefficient that is 0, or very close to 0, indicates that there is no correlation between the two factors examined.

A high absolute value of the correlation coefficient corresponds to a better correlation, where 1 represents an ideal correlation (Frisk, 2018).

A strong correlation is not necessarily equal to a linear correlation between the factors examined, an exponentially or logarithmic correlation may just as well be the better fit. In this thesis was Pearson's correlation coefficient used, which evaluates the linear correlation. However, a strong linear correlation might suggest a further evaluation.

Through a correlation matrix all correlation coefficients between all variables could be analyzed at once, including a collinearity analysis between the independent variables. Collinearity occurs when two variables correlate due to mutual, underlying factors, or when the data used is compositional, for example percentage of the same data set, as for the age groups. If variables with collinearity are combined in a linear regression model, the result will be unstable. If the absolute value of the correlation coefficient is higher than 0.7, it validates collinearity (Dormann et al., 2013).

Strong correlation was defined in this thesis as absolute values of the correlation coefficient higher than 0.7, as for collinearity. Weak correlation was defined as absolute values of the correlation coefficient below 0.3. In addition, intermediate correlation was defined as absolute values between 0.5 and 0.7 and moderate correlation as absolute values between 0.3 and 0.5. The correlation coefficient between the dependent variable and the independent variables was examined to determine relevance of further analysis. If collinearity was found between two independent variables, they were further analyzed and if one variable needed to be omitted, the one with the lowest correlation was chosen.

However, it is important to remember that correlations do not necessarily imply causations (Lukanov and Krieger, 2019). A correlation between two variables does not mean that the variables affect each other. However, it increases the probability. In this thesis, two correlation matrices were created, one for PV and one for ST. The data set used was the private residential data set for the three municipalities combined, without any modification. Thus, it is important to notice that some variables might show a weaker correlation combined due to differences in, for example, average income and level of education for the municipalities. In other words, the installed amount of solar energy systems might be centered around different average income, for example, which could affect the linear correlation when the data is combined.

To evaluate possible differences between the municipalities, a correlation coefficient between the dependent variable and each independent variable was calculated for the three municipalities. In addition, correlation coefficients were determined for the different types of DeSOs within the three municipalities: rural area (A), urban area outside the regional center (B) and regional center (C). Thus, the correlation between number of installed solar energy systems per household and the different socioeconomic and demographic factors could be evaluated at three different levels.

3.4.3 Regression analysis

Pearson's correlation coefficient made it possible to check if a correlation existed between two parameters, determine the size of it and whether it was positive or negative. However, it did not enable further analysis of the relationship or create a model that fitted the analyzed data. Regression analysis is a statistical process for estimating the relationship between a dependent variable (the outcome or the result to analyze) and one, or several, independent variables (the investigated, possible, explanatory variables). The most common form is linear regression, but exponential, polynomial and logarithmic regression is also common, depending on the context. A high correlation coefficient indicates that a possible well-adapted model can be created but nothing about the type of the best fitted model. If Pearson's correlation coefficient is used, as in this thesis, a high correlation coefficient indicates a well-fitted linear model.

To evaluate the fit of the model to the data, R-squared can be used. R-squared can be interpreted as the proportion of variance of the dependent variable explained by the regression model (defined in Equation 2). R-square is a number between 0 and 1, where a larger value corresponds to a better fitted model.

ʹYʹ ρ $\frac{\text{B ڎ ٩ ڎ ۶}}{\text{B ڎ ٩ ڎ ۶}}$ (2)

If a correlation was found between installed PV or ST systems and the analyzed independent variables, several regression models were created, plotted, and analyzed for each factor. The analyzed models were of the types: linear (defined in Equation 3), polynomial of the second degree (defined in Equation 4), logarithmic (defined in Equation 5) and exponential (defined in Equation 6). The models are calculated for two variables (x and y) with unique regression coefficients that describe the relationship between x and y for each set of variables.

ώ ῴ ὼ ῷ (3)

ώ ῴὼ˙ ῷ ὼ ῷ (4)

ώ ῴ ˈ ῴ ῷ (5)

ώ ῴΏ ڎ (6)

The models were evaluated in terms of R-square to determine the type of model best-fitted for the analyzed variables. A simple model is often preferred, which motivates a comparison between a linear regression model and the best-fitted of the three other types (polynomial of the second degree, exponential, logarithmic). As a result, this comparison was performed for each analyzed independent variable.

3.4.4 Sensitivity analysis

The result from the correlation and regression analysis is evaluated further through a sensitivity analysis. A sensitivity analysis is performed to assess the stability of a model or result with changed conditions. In this thesis, a relative low number of DeSOs (53 in total) are analyzed. This could be a source of error as individual DeSOs could have a large impact on the result. Based on this, the result for PV systems presented in the regression analysis was evaluated with focus on outliers. Further, a comparison of correlation coefficients and regression models between all analyzed DeSOs and DeSOs with outliers excluded was performed for chosen demographic variables.

4. Data

This thesis centers around data collection and different levels and sources of data. In this section data is used as the basis for the analysis further described. A short introduction and how the data were used have been described in Section 3. As a result, this section includes details about material and data bases that have been used in the inventory of solar energy systems, details about purposes of real properties and buildings available through Lantmäteriet, and socioeconomic and demographic data available through Statistics Sweden and Ratsit.

4.1 Identification of solar energy systems

In order to identify solar energy systems in this thesis, the tool Afrödull was used, along with cross-checking with different data bases. In this section the aerial imagery (orthophotos) used by Afrödull as well as DSOs and the Swedish direct capital Subsidy programme is further described.

4.1.1 Orthophotos

Orthophotos are radiometrically processed aerial photography data that are geometrically projected to an orthogonal map projection by using an elevation model. This means that unlike an aerial photo with central projection, the scale or distance between points in an orthophoto are not affected by variations in the terrain. Orthophotos produced and provided by Lantmäteriet is available for the whole territory of Sweden, with an exception for surfaces only consisting of open water (Lantmäteriet, 2019b).

The resolution of the orthophotos is 0.16 m per pixel and the type is 4-channel (red, green, blue, infrared). The aerial photos were taken during July 2019 for Knivsta and May and June 2020 for Falun and Uppvidinge. The photos were used to identify solar energy systems through Afrödull. They also make it possible to estimate the area of the solar energy systems, even though different tilts of the systems have not been accounted for so far.

4.1.2 Swedish direct capital Subsidy programme

Between the years of 2009 and 2020 the Swedish direct capital Subsidy programme was an available as a one-time state investment aid for installation of PV systems. The purpose of the regulation of the investment aid was to contribute to the transformation of the energy system and industrial development by increasing the use of PV systems and the annual electricity production from PV systems, the number of actors engaged and reducing the prices of PV systems (Riksdagsförvaltningen, 2021).

The investment aid was available for one PV system per building, or one PV system per real property if the system was ground-mounted, and could be applied for by individuals, companies and municipalities. For hybrid systems with combined production of solar PV and solar thermal, PVT systems, the electricity production needed to account for 20 percent of the system's estimated total annual electricity and heat production. Eligible costs were project, material, and labor costs. The aid could at max be 10 percent or 1.2 million SEK per PV or PVT system (Riksdagsförvaltningen, 2021).

Information from the Swedish direct capital Subsidy programme’s database, called SVANEN, contains the property designation of the real property where the PV system is located, installed capacity, type of owner, classification of the type of building, total area of the modules in some cases and date for reported commission of the PV system. The property designation from the database of granted PV investment aids was used as a complement in the identification of PV systems. However, since the investment aid was voluntary there is no guarantee that the database covers all actual systems, and this was confirmed in the research project that this thesis is a part of.

4.1.3 Distributed Systems Operators

Sweden’s electricity grid consists of transmission power lines and distribution power lines. Electricity grid companies have a monopoly to build grid lines within a certain specified area, and to be able to own and operate electricity power lines a special permit is required. In Sweden, Svenska kraftnät is the transmission system owner and operator (TSO), and the transmission power lines transports electricity from the large electricity producers to the regional distribution power lines. The distribution power lines are divided into regional and local power lines which are owned by large and small distribution system operators (DSO:s) (Svenska kraftnät, 2021).

If a producer of electricity wants to fed electricity into the grid, contact with the local DSO who manages the electricity grid is mandatory. Before an PV installation, the DSO decides how the system should be connected to the grid and which requirements the system needs to meet. The owner of the PV system together with the installer is responsible to fulfill and report these requirements, while the DSO is responsible to make sure that the conditions for the connection exist. After the installations, a final notification must be sent to the DSO by the electrical installation company (Energimyndigheten, 2022b).

The DSO is obliged to measure the amount of produced electricity that goes into the electricity grid per hour. For systems connected to the grid that do not feed more electricity into the grid than it uses annually, with a fuse of maximum 63 amperes and electricity production of maximum 43.5 kW, there is no fee for the connection to the grid. For systems below 1500 kW that produce more than it uses the connection fee is reduced (Energimyndigheten, 2022b).

The DSOs collects information containing the property designation, installed capacity and date of commission for PV installations within its area. By collaboration with the local DSOs in the investigated municipalities it was possible to complete the identification of PV systems.

4.2 Real properties and buildings characteristics

Lantmäteriet is an authority that maps Sweden and provides information on geography and real properties in the country. Lantmäteriet is responsible for registration of ownership and boundaries for all real properties in Sweden, which can be accessed through the Real Property Register (Lantmäteriet, 2022a). A real property is land divided into an owner share with a classification that consists of a district name, along with a block and unit number (the property designation), for example Kronåsen 7:1. Changes take place by authority decision and the real property classification is continuously updated (Lantmäteriet, 2019a). All data included in this section is produced and provided by Lantmäteriet.

Through Lantmäteriet information about both real properties and buildings was available for this thesis. The difference is the fact that several buildings can be located in the same real property and have different purposes within a property that only have one general purpose. In this section both data regarding properties and building is presented since they are provided by the same authority.

Data available at real property level through Lantmäteriet are property purpose, legal owner, taxed owner, tax unit’s area, tax value of land, tax value of buildings and total tax value of the tax unit (Lantmäteriet, 2021). The purpose of a real property is classified through the Swedish Tax Agency’s type codes for property assessment. The type codes are divided into eight main categories: (1) Agriculture units, (2) Single-family dwelling units, (3) Tenement building units, (4) Industrial premises units, (5) Owner occupied flats, (6) Quarries, (7) Power-generation units and (8) Special units (tax-free and free of charge), defined in Table 4. For each main category there are several specific purposes available (Skatteverket, 2022b; Skatteverket, 2022c).

Table 4: Different types of general purposes for properties categorized by Lantmäteriet.

General purpose of property	Definition
Agriculture	Farm building, land for cultivation/pasture and productive forest land. Detached houses and plots of land for detached houses located on agricultural property
Single-family dwelling	Detached houses and plots of land for such a building
Tenement building	Tenements and plot of land for such a building
Industrial premises	Industrial building, other buildings, land for such buildings as well as certain waterworks and fishing property
Owner occupied flats	Condominiums and plot of land for such a building
Quarries	Extension land as well as industrial buildings and other buildings on such land
Power-generation	Power plant building, land for power plant building and taxation unit whose value predominantly consists of the right to share- or replacement power
Special	Special buildings and plot of land for such a building

Information provided by Lantmäteriet about the type of owner of a real property shows whether it is owned by an individual or a company. The legal owner of the property refers to the person or company that holds the legal registration for the property, i.e., is registered as the owner of the real property. The taxed owner refers to the person or company who pays the property fee or property tax, which usually also is the legal owner (Lantmäteriet, 2022b). However, information about the legal owner was unavailable for some real properties with solar energy systems in the chosen municipalities and the legal owner was therefore, if necessary, assumed to be the same as the taxed owner. The tax unit's area is available in square meters and tax value for the total property. The value of the land area on the property and the building on the property is available in SEK. The tax value was calculated by Sweden's Tax Agency (Lantmäteriet, 2021).

The Real Property Register also includes information about buildings and their purpose. A building is defined, in the building section in the register, as a sustainable construction that consists of a roof or roof and walls, and that has a permanent location and construction that enable people to reside in it. The purpose that a building is used for is divided into seven different categories: (1) Residential, (2) Industrial, (3) Public, (4) Commercial, (5) Agriculture, (6) Complementary and (7) Other buildings, which are defined in Table 5. If a building has several purposes, the building is categorized after its main purpose. For buildings with the building purpose of (1) Residential, (2) Industry and (3) Public detailed purposes are available (Lantmäteriet, 2019a).

Table 5: Different types of general purposes for building categorized by Lantmäteriet.

General purpose of building	Definition
Residential	Building that is predominantly used for permanent or leisure accommodation
Industrial	Building that is predominantly used for the manufacture of products or processing of raw materials
Public	Building that is predominantly used for citizens' activities in a public context
Commercial	Building that is predominantly used for commercial purposes. E.g., hotel, office, retail shop, restaurant or car park
Agricultural	Building that is predominantly used for agricultural, forestry or comparable industry
Complementary	Building belonging to other buildings with residential, social function, business or industrial purposes. E.g., outhouse, garage, carport, cistern, storeroom, boathouse or garden shed. Buildings without walls may be included
Other building	Building whose purpose is not Residential, Industrial, Social, Commercial, Agricultural or Complementary. E.g., allotment cottage, detached, roof larger than 15 m^2 of durable construction

4.3 Socioeconomic and demographic data

Available socioeconomic and demographic data was collected from two sources: Statistics Sweden and Ratsit. In this section is the different data used presented in its' original form divided by type of source.

4.3.1 Statistics Sweden

Statistics Sweden is a statistical authority responsible for official statistics in Sweden, which include developing, producing and disseminating the statistics. Statistics Sweden's main task is to provide statistics for research, decision-making and debate for users and customers and coordinate Sweden's system for official statistics (Statistics Sweden, 2022a).

Statistics Sweden provides statistics on different levels of aggregation for Sweden. In this thesis two different levels were used, municipality and demographic statistical area (DeSO). There are 290 municipalities of different sizes in Sweden and this thesis analyzes the municipalities Falun, Knivsta and Uppvidinge. DeSOs are a nationwide and fixed division of municipalities into smaller areas implemented in 2018 (Statistics Sweden, 2022c).

Since the DeSOs follow the boundaries of municipalities, the socioeconomic and demographic data that are available for DeSOs are also available for municipalities in a corresponding format. Data that can be retrieved at this level through Statistics Sweden includes total population, age, sex, birth region, education, unemployment, average income, and economic standard (disposable income per consumption unit).

The population by age is presented through average age for the population in the municipality and seven age groups for DeSOs: 0-6 years, 7-15 years, 16-19 years, 20-24 years, 25-44 years, 45-64 years and over 65 years. The reported age is the age at the end of each year. The population by sex is presented as men and women (Statistics Sweden, 2018). Birth regions are divided into three groups, Sweden, Europe except Sweden and the rest of the world which includes persons for which data is not available (Statistics Sweden, 2022d).

The population between 25 and 64 years are divided into five groups by level of education. The groups are pre-high school, high school, post-high school less than three years, post-high school of three years or longer including doctoral studies and a group for whom data is not available. The information about level of education refers to the person’s highest education and is classified according to the Swedish Education Nomenclature. Unemployment is expressed through two groups, employed and unemployed, available for the population between 20 and 64 years (Statistics Sweden, 2018).

Average income is available for the population over 20 years. Income is the aggregated earned income which is the sum of income from employment and business activities. It consists of the current taxable income, which refers to income from employment, business/entrepreneurship, pension, sick pay and other taxable transfers. Aggregate earned income does not include capital income (Statistics Sweden, 2022f).

Economic standard is available for households’ inhabitants with an age of over 20 years, and is calculated as disposable income per consumption unit, which makes it possible to compare different households’ economic standards and take different compositions of households into account. Economic standard is available as an average for households and a division into four groups; Low for less than 167 400 SEK per consumption unit, MLow for 167 401 to 241 464 SEK per consumption unit, MHigh for 241 465 to 333 192 SEK per consumption unit and High for over 333 193 SEK per consumption unit (Statistics Sweden, 2018).

4.3.2 Ratsit

Ratsit is an internet-based company with a database that provides public information about individuals and companies. Available information includes for example age, sex and registration address for individuals (Ratsit, 2022a). Ratsit also provides a Taxation Calendar which contains information about income, capital, and average income for each municipality in Sweden. Income is the sum of income from employment and income from business activities. Capital includes other income and expenditures, for example dividend from shares, profit from the sale of assets and interest expenses. The sum of capital can therefore be both positive and negative (Ratsit, 2022b).

5. Results

In these sections, the results are presented, which includes both a compilation of the 1091 inventoried solar energy systems, a correlation and regression analysis as well as a sensitivity analysis. All data presented is valid for the year of 2020, this includes for example: income, age, and number of installed systems. The inventory of solar energy systems is divided into two parts: (1) solar photovoltaic (PV) and (2) solar thermal (ST) systems, which also applies for the sections presenting the result of the correlation and regression analysis. Vertical PV systems, which was identified by the cross-check with the local DSO and on-site inspections, are included in PV system inventory.

5.1 Total inventoried solar energy systems

The inventory of solar energy systems in the three municipalities Falun, Knivsta and Uppvidinge resulted in a data set consisting of four different types of systems: PV, BIPV, vertical PV and ST. It should be noted that vertical PV systems was identified in Falun only. In total, 1091 systems were identified through Afrödull, the database of the Swedish direct capital Subsidy programme, the database of the DSO's and on-site inspections. The percentage distribution in terms of quantity between PV (including vertical PV), ST and BIPV is presented in Figure 8. Around 63% of the identified systems are of type PV and almost 37% are ST systems. BIPV only accounts for 0.8%.

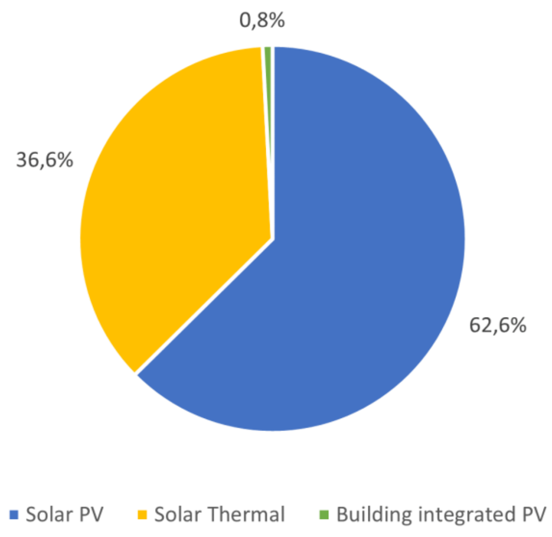

Figure 8 Number of solar energy systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between the types: solar PV (including vertical PV), solar thermal and building integrated PV

In total 692 PV systems (including 40 vertical PV and 9 BIPV) and 399 ST systems were identified. Data retrieved in the inventory for the two different solar energy types is presented in the following sections.

5.2 Solar photovoltaic

The inventory of PV systems (including vertical PV) is presented in this section in four different divisions: different types of DeSO areas (rural, urban, and regional center), type of properties, type of buildings and characteristics of the households within the private residential PV systems data set. A summary section is included in the end to sum up.

5.2.1 Rural, urban, and regional center areas

Each of the investigated municipalities is divided into DeSOs of three different types. The types of DeSOs are *mainly rural area* (A), *mainly urban area outside of the regional center* (B) and *mainly regional center* (C). Falun municipality consists of six rural areas, five urban areas and 26 regional center areas. Knivsta municipality consists of three rural areas, no urban areas and seven regional center areas. Uppvidinge municipality consists of two rural areas, two urban areas and two regional center areas. The result of the inventory of number of solar PV systems in the municipalities regarding type of DeSO is presented in Figure 9. Most of the systems were found to be in areas associated with the regional center in the municipalities or rural areas, while urban areas outside of the regional center accounted for the smallest share.

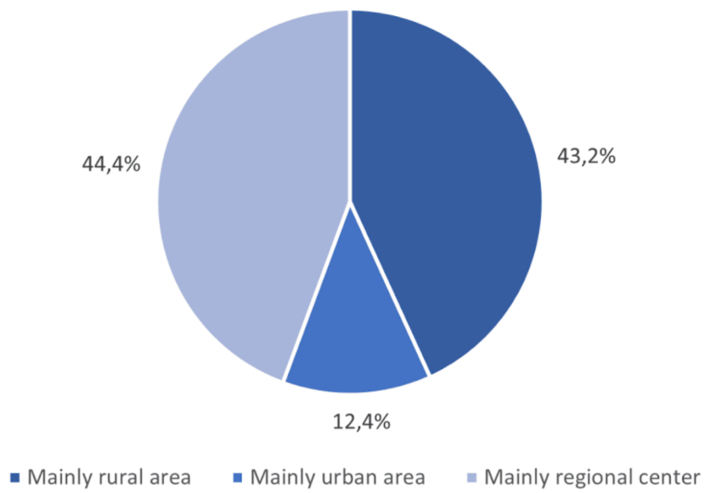

Figure 9: Number of PV systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between the DeSO types: rural area, urban area outside regional center and regional center.

The investigated municipalities vary in terms of size and population, the distribution between different types of DeSOs is therefore presented in Figure 10 in terms of number of PV systems per 1000 inhabitants in Falun, Knivsta, Uppvidinge, and as a total. PV systems in rural areas have the highest density for all municipalities and regional center areas the lowest. Uppvidinge rural areas account for the largest number of PV systems per 1000 inhabitants. In Knivsta, there is no DeSO of type urban area, which explains the zero value for this area. The municipalities' varying size of population result in a differentiated weight in the total. It should be noted that no consideration was taken into account regarding type of buildings or building concentration in relation to population in the different DeSO areas.

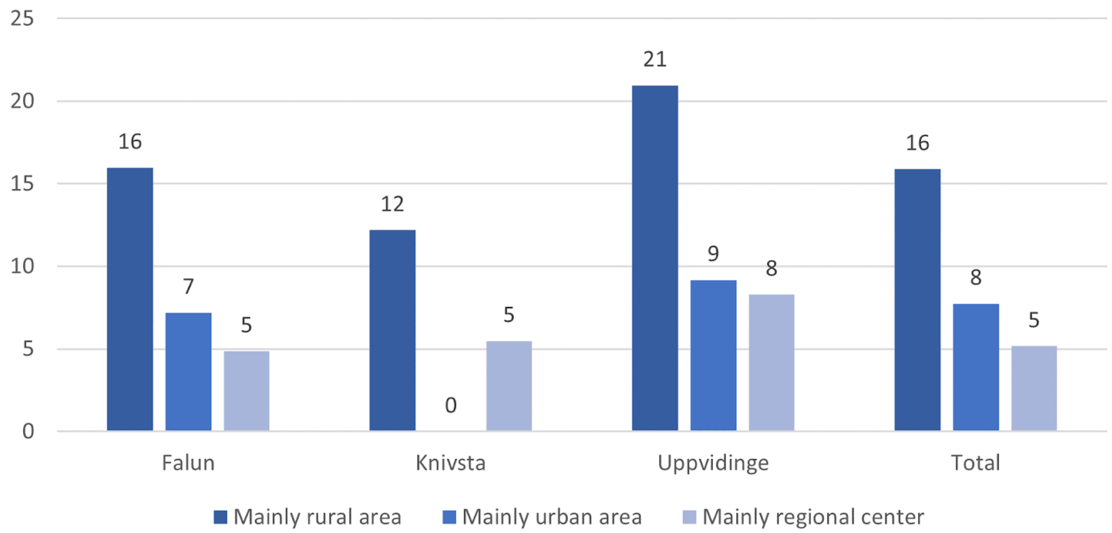

Figure 10: Total installed number of PV systems per 1000 inhabitants at the time of the respective aerial images in Falun, Knivsta, Uppvidinge, and total, for the DeSO types: rural area, urban area outside regional center and regional center.

5.2.2 Type of properties

Through Lantmäteriet, the property designation and type of property were extracted for all solar energy systems. There are eight different general categories of properties and several detailed categories for each general category. The total number of installed PV systems in the three municipalities distributed between the different general categories *agriculture, single-family dwelling, tenement building, industrial premises, owner occupied flats, quarries, power-generation* and *special* is presented in Figure 11. Around 66% of the systems is installed at properties with the general-purpose *single-family dwellings*, 91% of those with the detailed purpose *built-up properties* and 8% with the detailed purpose *residential value below 50 000 SEK*. Circa 20% of the PV systems were installed at properties generally categorized as *agriculture*, and 98% of those with the detailed purpose *built-up properties*. It should be noted that for some few properties, there were more than one PV system installed. This means that there are fewer properties than number of systems, i.e., each real property only calculated once.

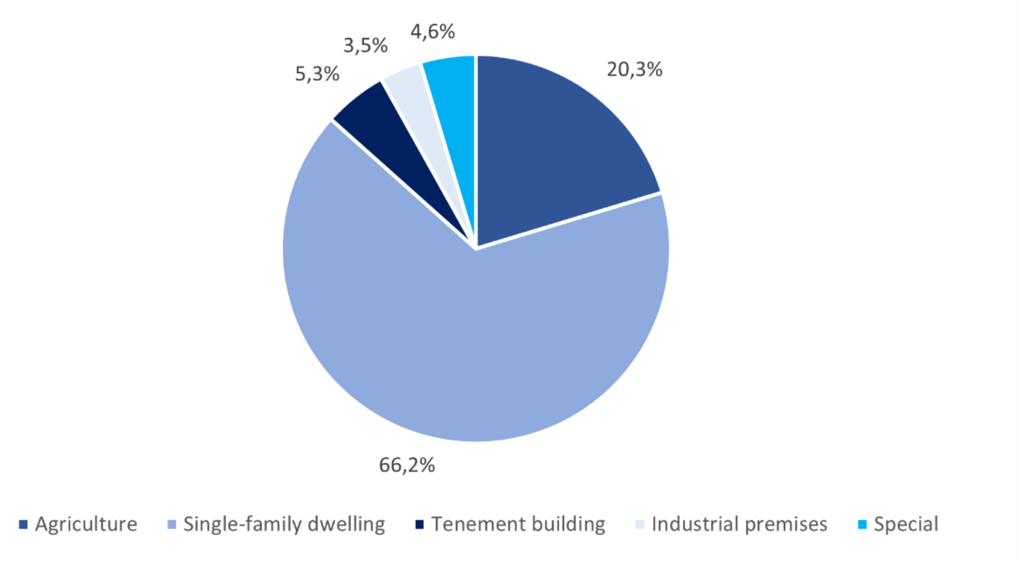

Figure 11: Number of PV systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between eight different categories of general purposes of properties.

Information about type of owner of each real property was available through Lantmäteriet. There are two types: individuals and companies. It was assumed that PV systems installed on properties owned by individuals are installed by individuals, and vice versa. The distribution between number of PV systems per type of owner is presented in Figure 12. Around 86% of the systems were installed by individuals.

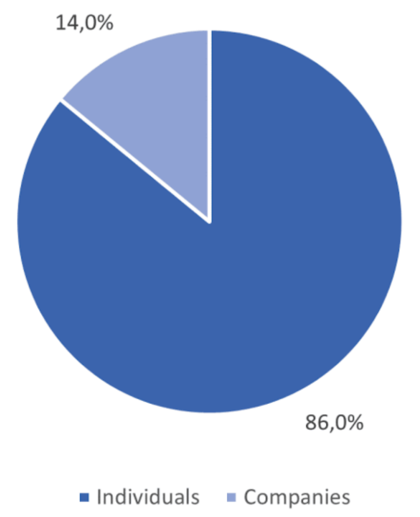

Figure 12: Number of PV systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between two types of owners of properties: individuals and companies.

The tax value for each property was available through Lantmäteriet as three numbers: taxable value of the land within a property, taxable value of building within a property and a total taxable value. The average and median total tax value for all properties with identified PV systems is presented in Table 6 for the three analyzed municipalities. All properties, including properties with more than one PV system, were calculated once. The result show that Knivsta has the highest average tax value of properties with installed PV systems, then Falun and Uppvidinge. A large difference between the average and median tax value might indicate a few properties with a significantly higher tax value.

Table 6: Average and median total tax value for all properties with PV systems in Falun, Knivsta and Uppvidinge

Municipality	Average tax value of properties	Median tax values of properties
Falun	4 040 500 SEK	2 283 000 SEK
Knivsta	5 429 400 SEK	3 794 000 SEK
Uppvidinge	2 479 300 SEK	914 000 SEK

5.2.3 Type of buildings

In addition to information regarding types of properties of installed systems are the types of buildings the PV systems have been installed on. Lantmäteriet categorize all building in Sweden in seven general types of buildings, each with several detailed purposes, including land. The general types of buildings are *residential, industrial, public, commercial, agricultural, complementary,* and *other building*. The number of PV systems identified in Falun, Knivsta and Uppvidinge is presented in Figure 13, distributed between the general building types. The largest number of PV systems was found to have been installed on *residential* (55%) and *complementary* (36%) buildings. Out of the PV systems installed on residential buildings are 85% installed on *small houses, detached*, 6% on *multi-family houses* and 6% on *small houses, chain linked*. All complementary buildings are *unspecified*. For PV systems installed on different buildings at the same real property, each building with a system is calculated once.

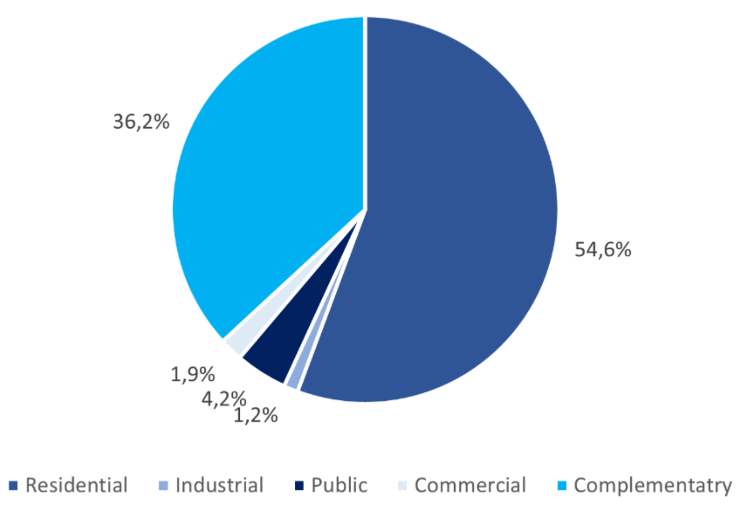

Figure 13: Number of PV systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between seven different categories of general purposes of building.

5.2.4 Household characteristics

Statistics Sweden provides statistics for each DeSO in the chosen municipalities, as well as for the municipalities themselves, and through Ratsit information about the households (all members over 20 years) in the private residential data set were available. The compilation method of the private residential data set along with made assumptions are presented in Section 3.3.2. Information about the households include average income, average age, sex, and average time living at the residence, for all members older than 20 years. Private residential PV systems have been identified in 47 out of the 53 DeSOs in this study. The DeSOs without systems are all of type *regional center* and are all located in Falun. In the following compilation are the six DeSOs without identified PV systems omitted.

The households with PV systems within each DeSO are summed up and compared to available general information about each DeSO. An average income of the households (members over 20 years) is compared to the average income of the DeSO and the difference in percent for each DeSO is presented in Figure 14 for Falun, Knivsta and Uppvidinge along with number of households in the private residential data set for each DeSO. Each bar represents one DeSO. The difference in percentage is presented instead of actual figures since the DeSOs and municipalities vary regarding average income.

The result show that a majority of the analyzed households have a higher average income than the average income of all inhabitants in their respective DeSO. There are however a few households with a lower average income than the average in the DeSO they belong to, which are further investigated. It was shown that there is either very few households with PV systems in these DeSOs, which makes it hard to draw a statistically sound conclusion and/or that the average age of these PV systems owners was high, around 60-75 years. In addition, one DeSO in Knivsta was shown to have a significantly higher difference compared to other. It was found that the households with PV within this DeSO have an unusual high average income.

It is also shown that the highest percentual differences are shown in DeSOs of type *regional center* for all three municipalities. For Falun and Uppvidinge, this type of DeSOs also account for the lowest and negative differences.

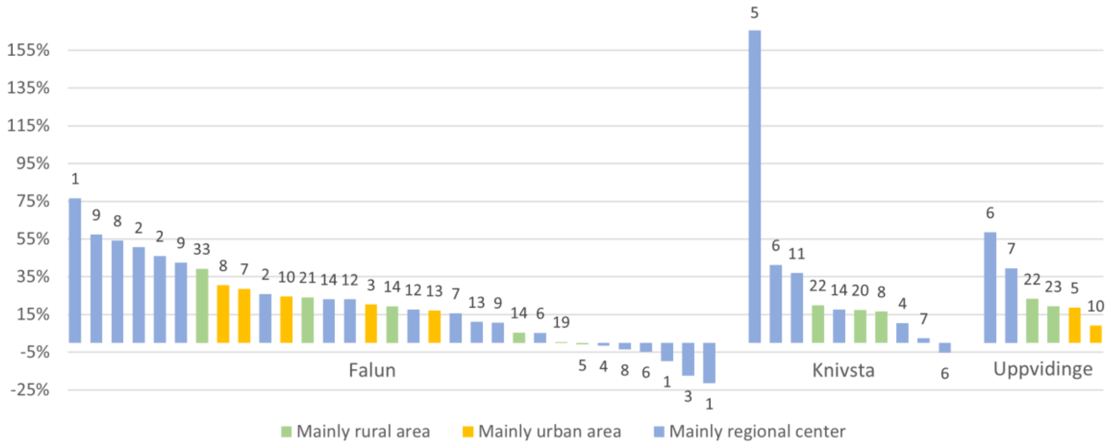

Figure 14: Difference in percent between the average income for households with PV systems in a DeSO and the respective average income in the same DeSO for Falun, Knivsta, Uppvidinge for all types of DeSOs. The number above the bar represents the number of households with a PV system in the private residential set for each DeSO. All figures are available in Appendix A.

A summarized result of the average income of the households with PV systems in the three municipalities is presented in Table 7 along with the average income in each municipality and the number of households with a PV system in the private residential data set. The result shows a similar difference around 25% between the average income of the households with PV systems as compared with the average income for all three municipalities.

Table 7: Average income for households with installed PV systems in the three municipalities, average income in each municipality, the difference between these and the number of households with PV systems in the private residential set for each municipality.

	Average income of households with PV systems	Average income of all households	Difference	Number of households with PV systems
Falun	411 500 SEK	329 500 SEK	25%	276
Knivsta	507 000 SEK	402 800 SEK	26%	103
Uppvidinge	356 000 SEK	285 800 SEK	25%	73

In addition to average income the average age and average time living at the residence of each household was available through Ratsit, which is presented in Table 8, along with average age of all residents in the municipalities. The result shows a higher average age of the analyzed households compared to the average age in each municipality, centered around 57 years. In addition, the average time living at the residence was found to be around 20 years.

Table 8: Average age and residence time of households with PV systems and average age of the municipalities for Falun, Knivsta and Uppvidinge

Municipality	Average age of households with PV systems	Average residence time of households	Average age of the municipality (20+)
Falun	57.9	22.1	51.8
Knivsta	54.4	17.1	48.3
Uppvidinge	58.9	23.7	53.3

Based on the sex of the members of each household an average sex was calculated as the percent of males. The summarized result of all households with a PV system within a municipality is presented and compared to percent males of each municipality in Table 9. It should be noted that the average sex of households was calculated for members over 20 years, while the average sex for the municipality is for all ages. The result shows a slightly higher percentage of males for households with PV systems in all municipalities, the most significant in Uppvidinge (54.8% compared to 52.3%).

Table 9: Average sex in terms of percent males for households with PV systems and average sex of all residents in the municipalities for Falun, Knivsta and Uppvidinge

Municipality	Average sex in the households with PV system	Average sex in the municipality as a whole
Falun	49.9%	49.6%
Knivsta	51.1%	51.0%
Uppvidinge	54.8%	52.3%

5.2.5 Summary

This section presents a short summary of the compilation of inventoried PV systems presented in Section 5.2. Almost 90% of the identified systems are installed at *mainly rural area* or *mainly regional center* (evenly distributed). In relation to capita are there a higher density installed PV systems in *mainly rural areas* for all municipalities. In addition, 86 % of the PV systems are installed by individuals. *Single-family dwellings* (66%) and *Agriculture* (20%) are the most common types of properties with installed PV systems. The average taxable value of the properties varies between 2 500 000 and 5 500 000 SEK depending on the municipality, where Knivsta has the highest value and Uppvidinge the lowest.

The most common buildings to install PV systems are *Residential* (55%) and *Complementary* (36%). Almost all the analyzed households within each DeSO are shown to have a higher average income than the average in their respective DeSO. A summary of all DeSOs show an average income for the households with PV systems that is around 25% higher than the average in all municipalities. The average age of the households is around 57 years for all municipalities, compared to an average age of around 48-53 years for the municipalities based on all people with an age above 20. In addition, the average living time at the residence for the analyzed households is around 20 years for all municipalities. It is also shown that the percentage males are slightly higher in the households with PV systems compared to the average in each municipality.

5.3 Solar thermal

The Solar thermal (ST) systems in the inventory are presented in four different divisions: different types of DeSO areas (rural, urban, and regional center), type of properties, type of buildings and characteristics of the households within the private residential ST systems data set. A short summary of the results in this section is included in the end.

5.3.1 Rural, urban, and regional center areas

The result of the inventory of ST systems in the three municipalities Falun, Knivsta and Uppvidinge includes number of ST systems installed in the different types of DeSOs: *mainly rural area* (A), *mainly urban area outside of the regional center* (B) and *regional center* (C), presented in Figure 15. The largest share (46%) of ST systems is installed in rural areas. The second largest share (36%) is installed in regional center areas and the smallest (18%) is installed in urban areas.

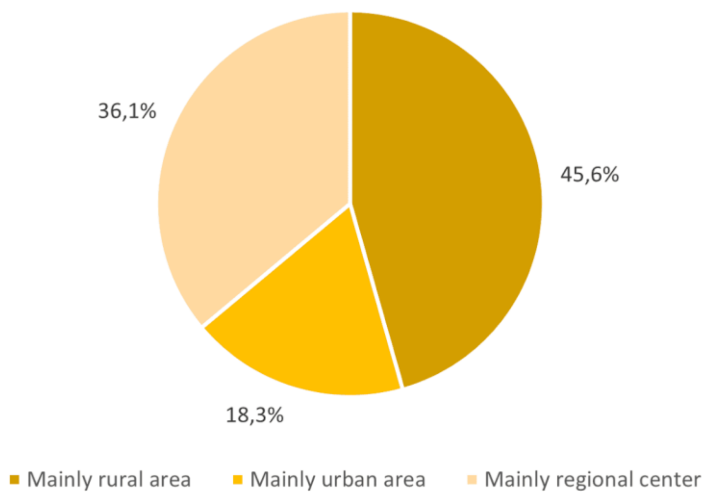

Figure 15: Number of ST systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between the DeSO types: rural area, urban area outside regional center and regional center.

Due to differences in terms of area and size of population for the three municipalities the result is presented in terms of number of ST systems per 1000 inhabitants for each municipality and as a total in Figure 16. There is a higher density of ST systems in Falun compared to Knivsta and Uppvidinge and the highest amount of ST systems per 1000 inhabitants is found in the rural areas of Falun. There is also a relative high density of ST systems installed in urban areas of Falun and urban areas of Knivsta. The is no DeSO of type urban area in Knivsta, which explains the zero value.

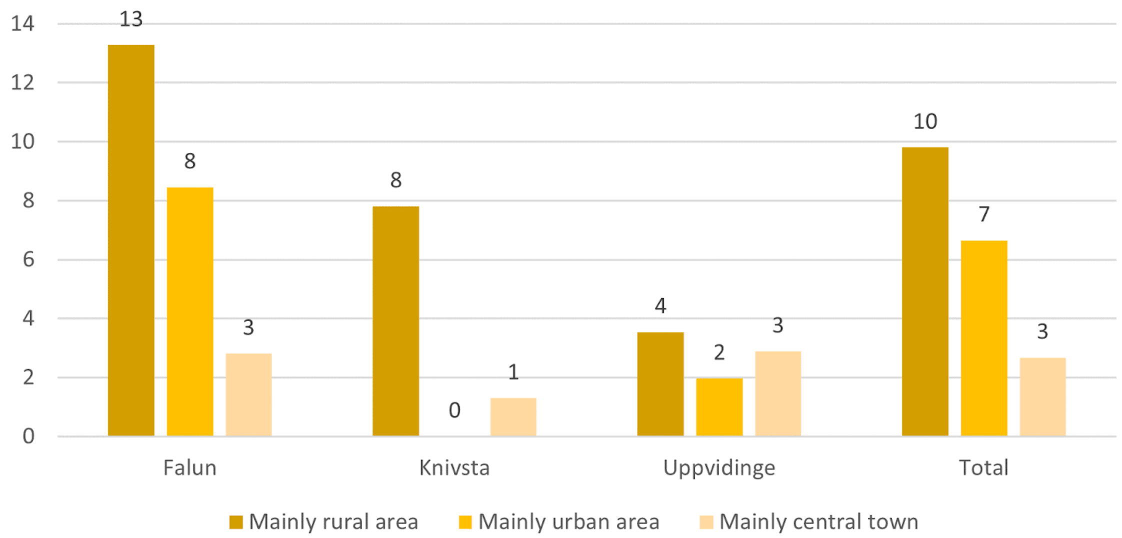

Figure 16: Total installed number of ST systems per 1000 inhabitants at the time of the respective aerial images in Falun, Knivsta, Uppvidinge, and total, for the DeSO types: rural area, urban area outside regional center and regional center.

5.3.2 Type of properties

Information regarding type of property is available for all ST systems in the three municipalities through Lantmäteriet. The distribution of ST systems between the eight groups of general purposes of properties is presented in Figure 17 *Single-family dwelling* properties accounts for the largest share of 72% and *agriculture* properties of 18%. The specified purpose is almost 100% *built-up* properties for both single-family dwelling and agriculture properties.

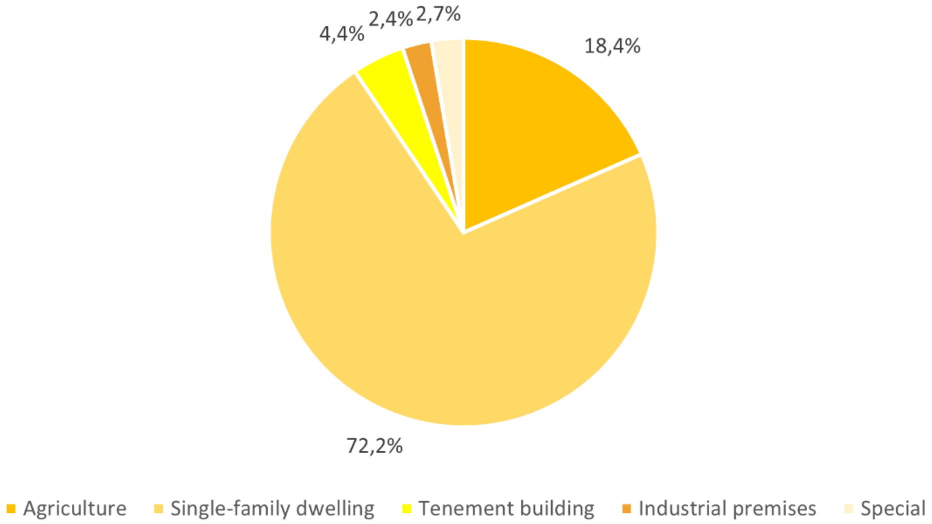

Figure 17: Number of ST systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between eight different categories of general purposes of properties.

Information about the properties with installed ST systems includes type of owner. The distribution between the two types of owners: individuals or companies, is presented in Figure 18. It is assumed that the owner of each real property is responsible for the installation of the ST system. The result show that individuals account for the largest number of systems, almost 96%.

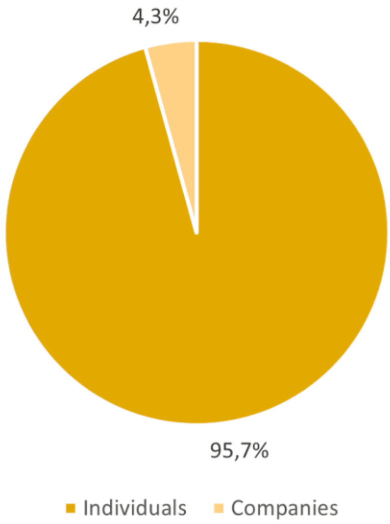

Figure 18: Number of ST systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between two types of owners of properties: individuals and companies.

Taxable value for each real property is available through Lantmäteriet in three different forms: taxable value of land within the property, taxable value for buildings within the property and total taxable value. The average and median total taxable value for all properties with ST systems in the three analyzed municipalities is presented in Table 10. The largest average tax value is found for Knivsta and the lowest for Uppvidinge. A larger difference between average and median might indicate a few properties with a significant higher tax value.

Table 10: Average and median tax value for all properties with ST systems in Falun, Knivsta and Uppvidinge

Municipality	Average tax value of properties	Median tax values of properties
Falun	3 043 981 SEK	1 987 500 SEK
Knivsta	3 692 175 SEK	3 155 000 SEK
Uppvidinge	1 646 154 SEK	716 500 SEK

5.3.3 Type of buildings

In addition to different types of properties with installed ST systems, information about type of building of each system is possible to extract from Lantmäteriet. Number of inventoried ST systems in the three municipalities in terms of type of building is presented in Figure 19**Fel! Hittar inte referenskälla.**. Out of eight different categories regarding general purposes are 77% installed on *residential* buildings and 21% on *complementary* buildings. The most common detailed purpose of ST systems installed on residential buildings is *small house, detached* (95%) and *small house, chain linked house* (3%). The only available detailed purpose of complementary buildings is *unspecified*.

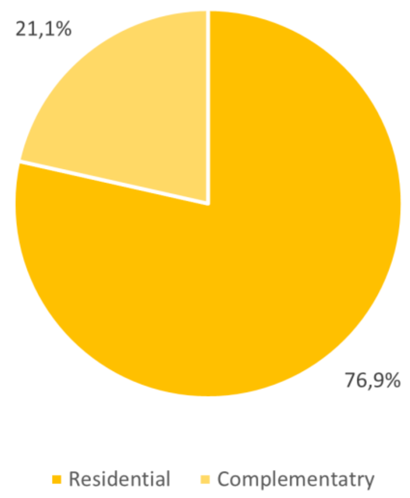

Figure 19: Number of ST systems in Falun, Knivsta and Uppvidinge at the time of the respective aerial images distributed between seven different categories of general purposes of building.

5.3.4 Household characteristics

Through Statistics Sweden statistics for each DeSO and municipality is available. The private residential data set of installed ST includes information about the households provided by Ratsit. The compilation of the private residential data set along with the made assumptions are presented in Section 3.3.2. Available information is average income, average age, sex, and average time at the residence, for all members older than 20 years. Private residential ST systems have been identified in 30 out of 37 DeSOs in Falun, 9 out of 10 DeSOs in Knivsta and in all DeSOs in Uppvidinge. DeSOs without ST systems are omitted in the following compilation, all of type *regional center*.

Households within a DeSO are summed up and the average income of households with ST systems is compared to average income of each DeSO and presented as a percentual difference in Figure 20 along with number of households in the private residential data set for each DeSO. Each bar along the x-axis represents a DeSO in the different municipalities. Since the DeSOs and municipalities vary regarding average income is the difference presented instead of actual figures.

The presented result show that the analyzed households within all DeSOs in the analyzed municipalities have a higher average income compared to the average income in each DeSO. A closer investigation of the DeSOs with a negative difference, i.e., a lower average income compared to the average of the DeSO, show an average age of around 60 years for these households (80 years for the household with the most negative difference). This might explain the result.

Overall, the result indicates that the largest difference in average income is shown in *regional center* DeSOs. In Falun are the DeSOs with the most negative difference also of this type. A weaker trend that can be observed is that DeSOs of type *rural areas* show a relative lower difference in average income and *urban areas* an average value.

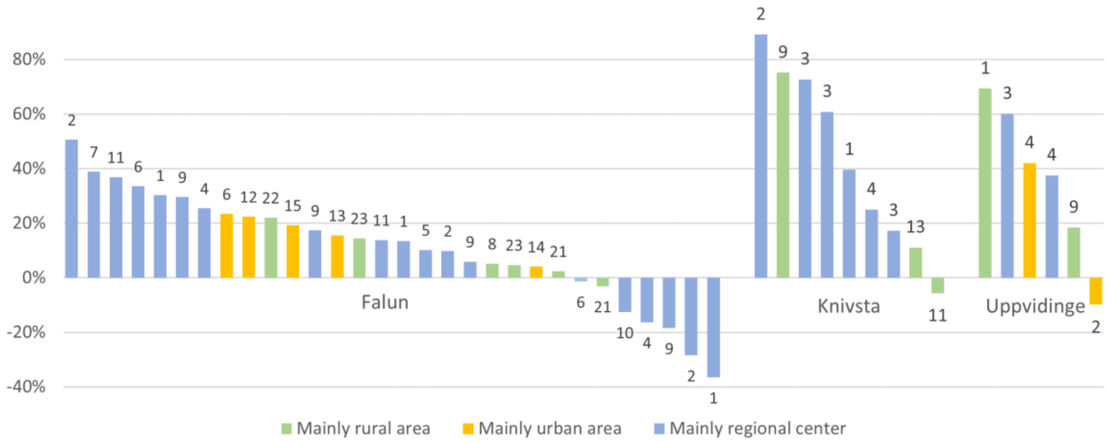

Figure 20: Difference in percent between the average income for households with ST systems in a DeSO and the respective average income in the same DeSO for Falun, Knivsta, Uppvidinge for all types of DeSOs. The number above the bar represents the number of households with a ST system in the private residential set for each DeSO. All figures are available in Appendix B.

A summarized result of the households with ST systems in the three municipalities in terms of average income is presented in Table 11 and compared with the average income in each municipality. A larger difference (around 30%) between households with PV and the average is shown in Knivsta and Uppvidinge, while a smaller difference (13%) is shown in Falun. However, the number of analyzed households is significantly higher in Falun compared to the other municipalities (287 compared vs 49 and 23).

Table 11: Average income for households with installed ST systems in the three municipalities, average income in each municipality, the difference between these and the number of households with PV systems in the private residential set for each municipality

	Average income of households with ST systems	Average income of all households	Difference	Number of households with ST systems
Falun	373 800 SEK	329 500 SEK	13%	287
Knivsta	533 600 SEK	402 800 SEK	32%	49
Uppvidinge	371 500 SEK	285 800 SEK	30%	23

Through Ratsit information was gathered about each household's average age and time living at the resident. A summarized average age and time at residence along with the average age of all residents in the municipality is presented in Table 12 for each municipality. The result shows a higher average age of the households with ST systems compared to the average for all municipalities. In addition, the average residence time can be centered around 20-25 years.

Table 12: Average age and residence time of households with ST systems and average age of all residents with an age above 20 years in the municipalities for Falun, Knivsta and Uppvidinge

Municipality	Average age of households with ST systems	Average residence time of households	Average age of the municipality (20+)
Falun	58.0	22.7	51.8
Knivsta	52.3	17.8	48.3
Uppvidinge	55.4	28.6	53.3

The summary of households within each DeSO includes information about the average sex. The average for households with ST systems is presented in Table 13 along with percent males for each municipality. The result shows a higher percentage of males in households with ST systems compared to the average for all municipalities. The largest differences are observed in Falun and Uppvidinge (54.8% and 55.1% compared to 49.6% and 52.3%, respectively). Only a slightly higher percentage of males is shown for households with ST systems in Knivsta.

Table 13: Average sex in terms of percent males for households with ST systems and average sex of all residents in the municipalities for Falun, Knivsta and Uppvidinge

Municipality	Average sex in the households with ST system	Average sex in the municipality as a whole
Falun	54.8%	49.6%
Knivsta	51.4%	51.0%
Uppvidinge	55.1%	52.3%

5.3.5 Summary

This section summarizes the result of the inventory of ST systems presented in Section 5.3. Out of the identified ST systems almost 46% was found to have been installed at mainly rural area, 36% at mainly regional center and around 18% at mainly urban area outside of the regional center. The highest amount of ST systems per 1000 inhabitants is observed in rural areas of Falun, then rural areas of Knivsta and then urban areas of Falun. The most common properties of installed ST systems are *Single-family dwelling* (72%) and *Agriculture* (18%). The average taxable value of the properties varies between 1 600 000 SEK and 3 000 000 depending on the municipality, with a higher in Knivsta and a lower in Uppvidinge. Almost 96% of the ST systems were installed by individuals.

The most common type of buildings for installed ST systems are *residential* (77%) and *complementary* (21%). The average income for analyzed households within each DeSO was found to be higher than the average for almost all DeSOs. A summary of the households with ST systems within each municipality show a higher average income compared to the average income in each municipality, around 30% for Knivsta and Uppvidinge and 13% for Falun. The average age of households with ST systems is around 55 years for all municipalities, which is higher than the average in each municipality (around 48-53 years). All averages ages are calculated for persons over 20 years. The average time living in the residence is around 20-25 years for households with ST systems. The result also shows a slightly higher percentage of males in households with ST compared to the average in each municipality.

5.4 Correlation analysis

The results from the correlation analysis are presented in this section in terms of correlation matrices and Pearson's correlation coefficient for the different municipalities and types of DeSOs for PV and ST systems separately.

5.4.1 Solar photovoltaic

A correlation matrix was created for the private residential PV data set in order to evaluate collinearity and correlation between the different variables. The data sets for the three municipalities have been combined to create a larger sample. No consideration has been given to the fact that the municipalities vary in terms of, for example, average income and education. The matrix is based on installed PV systems per household in each DeSO and the, through Statistics Sweden, retrieved statistics for each DeSO. DeSOs, in which no systems are identified, are omitted due to lack of data. As a result, 47 DeSOs, out of total 53 DeSOs, have been processed for PV systems.

The correlation matrix, consisting of the correlation between all dependent and independent variables, for PV systems is presented in Table 14. The correlation coefficients in the table are colored with four different shades of blue, the darkest shade corresponding to a high correlation and the lightest corresponds to a weak correlation. The diagonal with ones is the correlation within each factor.

Collinearity for PV systems was found between age group 0-15 years and 65+ years, 25-44 years and 45-64 years, birth region and unemployment, education and average income, unemployment and variables describing economic conditions, and within the economic condition variables. The result was expected for the age groups due to compositional data and for the economic conditions due the use of same data base. Independent variables that showed a moderate correlation to the dependent variable PV system per household are age group 16-24 years, 25-44 years, and birth region only birth region showed a positive correlation. An intermediate correlation was observed for age groups 45-64 and sex.

Table 14: Correlation matrix with Pearsonôs corr
PV systems per household and different demographic factors for all DeSOs with installed systems in the municipalities Falun, Knivsta and Uppvidinge combined.

	PV	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
PV	1	-0.09	-0.44	-0.41	0.52	0.18	0.56	0.32	-0.22	-0.15	0.00	0.18	-0.19	0.18
0-15	-0.09	1	0.16	0.50	-0.39	-0.90	0.01	-0.07	0.38	-0.34	0.66	0.38	-0.47	0.42
16-24	-0.44	0.16	1	0.21	-0.35	-0.34	-0.23	-0.51	0.28	0.35	0.14	-0.04	0.22	-0.03
25-44	-0.41	0.50	0.21	1	-0.74	-0.67	-0.20	-0.35	0.23	0.07	0.21	-0.05	-0.04	-0.05
45-64	0.52	-0.39	-0.35	-0.74	1	0.34	0.51	0.42	-0.22	-0.19	-0.01	0.27	-0.24	0.27
65+	0.18	-0.90	-0.34	-0.67	0.34	1	-0.07	0.19	-0.39	0.21	-0.65	-0.37	0.43	-0.41
Sex	0.56	0.01	-0.23	-0.20	0.51	-0.07	1	0.05	-0.49	0.02	-0.07	0.01	-0.13	0.07
BReg	0.32	-0.07	-0.51	-0.35	0.42	0.19	0.05	1	0.28	-0.75	0.33	0.39	-0.59	0.40
Educ	-0.22	0.38	0.28	0.23	-0.22	-0.39	-0.49	0.28	1	-0.50	0.76	0.66	-0.60	0.66
UEm	-0.15	-0.34	0.35	0.07	-0.19	0.21	0.02	-0.75	-0.50	1	-0.71	-0.71	0.89	-0.71
AInc	0.00	0.66	0.14	0.21	-0.01	-0.65	-0.07	0.33	0.76	-0.71	1	0.85	-0.84	0.89
EcSt	0.18	0.38	-0.04	-0.05	0.27	-0.37	0.01	0.39	0.66	-0.71	0.85	1	-0.87	0.96
LInc	-0.19	-0.47	0.22	-0.04	-0.24	0.43	-0.13	-0.59	-0.60	0.89	-0.84	-0.87	1	-0.87
HInc	0.18	0.42	-0.03	-0.05	0.27	-0.41	0.07	0.40	0.66	-0.71	0.89	0.96	-0.87	1

The presented correlation matrix did not take differences between the municipalities in terms of, for example, average income and education into account. This might have resulted in a weaker correlation between the different variables. Thus, Pearson's correlation coefficient between PV systems per household and each independent variable is presented for the three municipalities separately in Table 15. For PV systems were 31 out of 37 DeSOs analyzed in Falun, all ten DeSOs in Knivsta and all six DeSOs in Uppvidinge. The result presented is in line with the result shown in Table 14 (except for sex and education) but with stronger correlations. The result is inconsistent regarding sex and education, with Uppvidinge found to have an opposite correlation compared to Falun and Knivsta. Strong and intermediate correlation is found for average economic standard in Knivsta and Uppvidinge, whilst only weak in Falun.

Table 15: P e a r s o n ô s   c o r r e l a t i o n   c o e f f i c i e n t   b e t w e and different demographic factors for all DeSOs with installed systems in the municipalities Falun, Knivsta and Uppvidinge

PV	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
Falun	-0.08	-0.38	-0.41	0.49	0.19	0.66	0.43	-0.24	-0.16	0.03	0.09	-0.26	0.15
Knivsta	-0.24	-0.50	-0.68	0.69	0.37	0.74	0.59	-0.20	-0.27	0.00	0.62	-0.30	0.54
Uppvidinge	-0.15	-0.81	-0.51	0.63	0.38	-0.22	0.87	0.62	-0.56	0.42	0.79	-0.48	0.76

Each DeSO is categorized as one of three types: rural area (A), urban area (B) or regional center (C), and each municipality is divided into the different types. PV systems in the private residential data set was identified in all six *rural area* DeSOs in Falun, all three *rural area* DeSOs in Knivsta and both *rural area* DeSOs in Uppvidinge. In Falun, PV systems was identified in all five *urban area* DeSOs and both *urban area* DeSOs in Uppvidinge. There are no *urban area* DeSOs in Knivsta. In addition, PV systems were identified in 20 out if 26 *regional center area* DeSOs in Falun, all seven *regional center area* DeSOs in Knivsta and both *regional center area* DeSOs in Uppvidinge.

Pearson's correlation coefficient between installed PV systems per household and the independent variables is presented for the three types of DeSOs (*rural, urban and regional center*) separately in Table 16. In total, eleven *rural area* DeSOs, seven *urban area* DeSOs and 29 *regional center area* DeSOs were analyzed. There are differences between the types for almost all variables, consistency is only shown for the variables 25-44 years and birth region. One trend that can be observed is that the correlation coefficient is more similar between type B and C, while commonly the opposite for type A. The strongest correlations are found in *urban area* DeSOs.

Table 16: P e a r s o n ô s ficient between installed PV systems per household and different demographic factors for DeSOs of type rural area (A), urban area (B) and regional center area (C) with installed systems in the municipalities Falun, Knivsta and Uppvidinge combined.

PV	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
A	-0.13	-0.52	-0.28	-0.08	0.31	0.38	0.21	-0.01	0.08	-0.13	-0.10	0.10	-0.01
B	-0.56	0.07	-0.62	0.51	0.35	-0.37	0.28	0.34	-0.52	0.56	0.59	-0.44	0.26
C	0.27	-0.11	-0.44	0.49	-0.13	0.54	0.35	0.11	-0.35	0.33	0.45	-0.42	0.44

5.4.2 Solar thermal

For the private residential ST data set a correlation matrix was created to evaluate the correlation and collinearity between the chosen variables. The correlation matrix was based on inventoried ST systems, expressed in installed systems per household, and statistics for each DeSO, available through Statistics Sweden. The data set of the three municipalities were combined to create a large data set. DeSOs without any identified systems were omitted due to lack of data. As a result, 45 DeSOs have been processed for ST systems, out of total 53 DeSOs. The fact that the municipalities vary in terms of average income and education, for example, have not been considered.

The correlation matrix for all variables is presented in Table 17. The correlation coefficients in the table are colored with four different shades of yellow, the darkest shade corresponding to a high correlation and the lightest corresponds to a weak correlation. The diagonal with ones represents the correlation within each factor.

For ST systems were collinearity found between age group 0-15 years and 65 years, birth region and unemployment, education and average income, unemployment and almost all variables describing economic conditions and within the economic condition variables. Moderate correlation was shown between ST systems per household and independent variable age group 16-24 years, 25-44 years, sex and unemployment. Intermediate correlation was found for age groups 45-64 and birth region.

Table 17: Correlation matrix with Pearsonôs corr
ST systems per household and different demographic factors for all DeSOs with installed systems in the municipalities Falun, Knivsta and Uppvidinge combined

	ST	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
ST	1	-0.16	-0.45	-0.50	0.56	0.25	0.33	0.58	-0.19	-0.31	-0.03	0.05	-0.25	0.09
0-15	-0.16	1	0.24	0.31	-0.24	-0.88	0.09	-0.13	0.40	-0.32	0.69	0.36	-0.48	0.52
16-24	-0.45	0.24	1	0.32	-0.44	-0.43	-0.23	-0.51	0.28	0.35	0.15	-0.05	0.24	-0.07
25-44	-0.50	0.31	0.32	1	-0.65	-0.56	-0.19	-0.37	0.19	0.12	0.22	0.08	-0.02	0.02
45-64	0.56	-0.24	-0.44	-0.65	1	0.20	0.52	0.46	-0.17	-0.24	0.01	0.24	-0.30	0.26
65+	0.25	-0.88	-0.43	-0.56	0.20	1	-0.14	0.23	-0.40	0.19	-0.69	-0.41	0.45	-0.51
Sex	0.33	0.09	-0.23	-0.19	0.52	-0.14	1	0.02	-0.45	0.00	-0.03	-0.01	-0.15	0.10
BReg	0.58	-0.13	-0.51	-0.37	0.46	0.23	0.02	1	0.29	-0.74	0.31	0.38	-0.58	0.39
Educ	-0.19	0.40	0.28	0.19	-0.17	-0.40	-0.45	0.29	1	-0.50	0.76	0.65	-0.61	0.67
UEm	-0.31	-0.32	0.35	0.12	-0.24	0.19	0.00	-0.74	-0.50	1	-0.70	-0.68	0.89	-0.72
AInc	-0.03	0.69	0.15	0.22	0.01	-0.69	-0.03	0.31	0.76	-0.70	1	0.81	-0.84	0.90
EcSt	0.05	0.36	-0.05	0.08	0.24	-0.41	-0.01	0.38	0.65	-0.68	0.81	1	-0.84	0.92
LInc	-0.25	-0.48	0.24	-0.02	-0.30	0.45	-0.15	-0.58	-0.61	0.89	-0.84	-0.84	1	-0.89
HInc	0.09	0.52	-0.07	0.02	0.26	-0.51	0.10	0.39	0.67	-0.72	0.90	0.92	-0.89	1

The presented correlation matrix did not take differences, for example in average income and education, between the municipalities into account, which might have resulted in weaker correlations in some cases. Pearson's correlation coefficient between ST systems per household and each independent variable is presented in Table 18 for the three municipalities separately. For ST systems were 30 out of 37 DeSOs analyzed in Falun, 9 out of 10 in Knivsta and 6 DeSOs in Uppvidinge.

The presented result in Table 18 could be interpreted as in line with the result observed in Table 17 for the independent variables age group 0-15 years, 25-44 years, 65+ years, education, unemployment, average income, and average economic standard. Stronger correlation for the municipalities separately compared to the combined result was found for some of these variables. For the variables age group 16-24 years, 45-64 years, sex and birth region was the results inconsistent for Uppvidinge, which was shown to have an opposite correlation compared to Falun and Knivsta. In addition, the correlation coefficient for Falun for the variables low economic standard and high economic standard were inconsistent with the previous result and the result for Knivsta and Uppvidinge.

Table 18: Pearsonôs correlation coefficient betwe and different demographic factors for all DeSOs with installed systems in the municipalities Falun, Knivsta and Uppvidinge

ST	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
Falun	0.08	-0.48	-0.62	0.66	0.14	0.57	0.59	-0.31	-0.40	0.13	0.15	-0.38	0.26
Knivsta	-0.55	-0.66	-0.32	0.67	0.50	0.79	0.45	-0.82	0.01	-0.38	0.02	0.08	-0.09
Uppvidinge	-0.55	0.29	-0.37	-0.12	0.48	-0.19	-0.31	-0.53	-0.17	-0.18	-0.29	0.23	-0.38

ST systems in the private residential data set was identified in all six *rural area* DeSOs in Falun, all three *rural area* DeSOs in Knivsta and both *rural area* DeSOs in Uppvidinge. For *urban area* DeSOs were ST systems identified in all five *urban area* DeSOs in Falun and both *urban area* DeSOs in Uppvidinge. There are no *urban area* DeSOs in Knivsta. Lastly ST systems were identified in 19 out if 26 *regional center area* DeSOs in Falun, six out of seven *regional center area* DeSOs in Knivsta and both *regional center area* DeSOs in Uppvidinge. As a result, eleven *rural area* DeSOs, seven *urban area* DeSOs and 27 *regional center area* DeSOs were analyzed.

Pearson's correlation coefficient between installed ST systems per household and the independent variables is presented for the three types of DeSOs (*rural, urban and regional center*) separately in Table 19. There are only a few variables showing consistency, for example the variables birth region, education, unemployment, average income and low economic standard. The strongest correlations are found for *urban area* DeSOs. It is hard to distinguish any clear trends, there are similarities between type A and B for some variables and between type B and C for some other variables.

Table 19: Pearsonôs correlation ST systems per household coefficient betwe and different demographic factors for DeSOs of type rural area (A), urban area (B) and regional center area (C) with installed systems in the municipalities Falun, Knivsta and Uppvidinge combined.

ST	0-15	16-24	25-44	45-64	65+	Sex	BReg	Educ	UEm	AInc	EcSt	LInc	HInc
A	-0.07	0.26	0.04	0.06	-0.05	-0.16	0.65	0.17	-0.21	0.09	-0.15	-0.29	-0.12
B	-0.35	-0.47	-0.80	-0.09	0.82	-0.70	0.82	0.89	-0.83	0.91	0.51	-0.61	0.58
C	0.06	-0.29	-0.58	0.58	0.09	0.33	0.48	0.15	-0.37	0.17	0.26	-0.34	0.33

5.4.3 Summary

This Section presents a summary of the results retrieved through the correlation analysis of installed PV and ST systems. The correlation matrix for PV systems showed intermediate positive correlation for the variables 45-64 years and sex, moderate positive correlation for birth region and moderate negative correlation for 16-24 years and 25-44 years. The remaining analyzed variables showed only a weak correlation. Collinearity was found between 0-15 years and 65+ years, 25-44 years and 45-64 years, birth region and unemployment, education and average income, unemployment and all economic condition variables, and within all economic condition variables.

The correlation analysis of the different municipalities separately showed, however, stronger correlations for almost all municipalities. Positive correlation, of different size, was found for 45-64 years, birth region, average economic standard, and high economic standard in all municipalities. Negative correlation, of different size, was observed for 0-15 years, 16-24 years, 25-44 years, unemployment, and low economic standard in all municipalities. The variables sex showed a (strong or intermediate) positive correlation in Falun and Knivsta, and a (weak) negative correlation in Uppvidinge. Education showed a (weak) negative correlation in Falun and Knivsta and a (strong) positive correlation in Uppvidinge.

The analysis of different types of DeSOs: rural (A), urban (B) and regional center (C) showed a variety of results. There seems to be, overall, stronger correlations for almost all variables in *urban area* and *regional center area* DeSOs, an often the opposite compared to *rural area* DeSOs. For example, the variables average income, economic standard and age group 45-64 years showed a (moderate or intermediate) positive correlation for type B and C, while a (weak) negative correlation for type A.

The correlation matrix for ST systems showed intermediate positive correlation for 45-64 years and birth region, moderate positive correlation for sex, negative intermediate correlation for 25-44 years and moderate negative correlation for 16-24 years and unemployment. The remaining analyzed variables showed weak correlation. Collinearity was found between 0-15 years and 65+ years, birth region and unemployment, average income and education, average income and unemployment, and within the variables related to economic conditions.

The analysis of the different municipalities separately showed similar results as the correlation matrix, with some variations. Positive correlation (of different sizes) was observed for 65+ years and negative correlation (of different sizes) for 25-44 years and education in all municipalities. For several of the variables was a opposite correlation observed in Uppvidinge compared to Falun and Knivsta. For example, a (intermediate) positive trend was found for 45-64, sex and birth region in Falun and Knivsta, whilst a (moderate) negative was found in Uppvidinge.

The result of the analysis of different DeSOs: rural (A), urban (B) and regional center (C) showed varied results. Strong correlations were only found for *urban area* DeSOs, and stronger correlations were shown in *urban area* and *regional center* area DeSOs compared to *rural area* DeSOs for almost all variables. The most consistent, and clearest, trend is found for birth region, where a positive trend is shown.

5.5 Regression analysis

Based on the installed solar energy systems in the municipalities combined and the result of the correlation analysis are some of the independent variables analyzed in this thesis chosen for further investigation. In this Section the result of the regression analysis of the different chosen variables is presented separately for PV and ST systems.

5.5.1 Solar photovoltaic

For PV systems, based on the correlation analysis, eight out of the 13 analyzed variables were chosen for regression analysis. The variables are 16-24 years, 45-64 years, sex, birth region, education, unemployment, low economic standard, and high economic standard. The two age groups 0-15 years and 65+ years showed a clear negative collinearity (-0.90) and was therefore further evaluated to decided which was to be omitted. However, since the correlation to installed PV system presented in the correlation matrix was weak for both 0-15 years (-0.09) and 65+ years (0.18), and they were the two age groups with the weakest correlation for each municipality, both were omitted.

In addition, the age groups 25-44 years (-0.41) and 45-64 years (0.52) showed collinearity (-0.74). As a result, the variable with the lowest correlation to installed PV systems, 25-44 years, was omitted from the regression analysis. Collinearity was also shown between birth region and unemployment (-0.75), and education and average income (0.76). This might be due to underlying common factors. However, since it is of interest to further analyze both birth region and unemployment, none of these was omitted. Collinearity was also observed between average income and: unemployment and average, low and high economic standard. In addition, the correlation between average income and PV systems was zero for all municipalities combined and weak (0.03; 0.00; 0.42) for the municipalities separately. Based on this, average income was omitted from further regression analysis.

Collinearity was also found within the variables representing different aspects of economic standard, since they are based on the same data set. The correlations to total installed PV systems were of similar size, 0.18 for average economic standard, -0.19 for low economic standard and 0.18 for high economic standard. All variables showed higher correlation for the municipalities separately, which indicates that the difference between the municipalities in average income might have resulted in a weaker correlation combined. The highest collinearity between the economic condition variables was 0.96, observed between average and high economic standard. Thus, average economic standard was omitted in order to minimize variables representing similar conditions while still maintain a comprehensive economic analysis, which low and high economic standard was assumed to provide. No collinearity was observed for the eighth variable, sex, and it was therefore further analyzed.

The data of the chosen variables were analyzed through four different forms of regression: linear, polynomial of the second degree, exponential and logarithmic. The different regression models were evaluated in terms of R-square in order to find the model best fitted to the data. As a result, are data points, a linear regression model (blue) and a polynomial regression model of the second degree (red) presented for each of the eight analyzed variables in Figure 21. The R-square values for the two models are presented in the corners of each plot. The linear model was chosen due to its simplicity and the polynomial model was shown to have the highest R-square of the other analyzed models (polynomial, exponential and logarithmic), for almost all of the analyzed variables. The only exception is sex, for which the exponential regression model showed the highest R-value. Still, the polynomial model was plotted for sex as well, to keep the plot consistent. The value of R-square for all models and variables is presented in Appendix C.

It is shown that the polynomial model of the second degree have a higher R-square than the linear model for all analyzed variables. The highest R-value (0.33) was observed for the polynomial model of sex. The lowest R-value (0.02) was found for the linear model of unemployment. This is consistent with the correlation coefficients in the correlation matrix, with the highest (0.56) for sex and lowest (-0.15) for unemployment. The clearest positive trends were identified for 45-64 years and sex, and the clearest negative trends were identified for 16-24 years and unemployment.

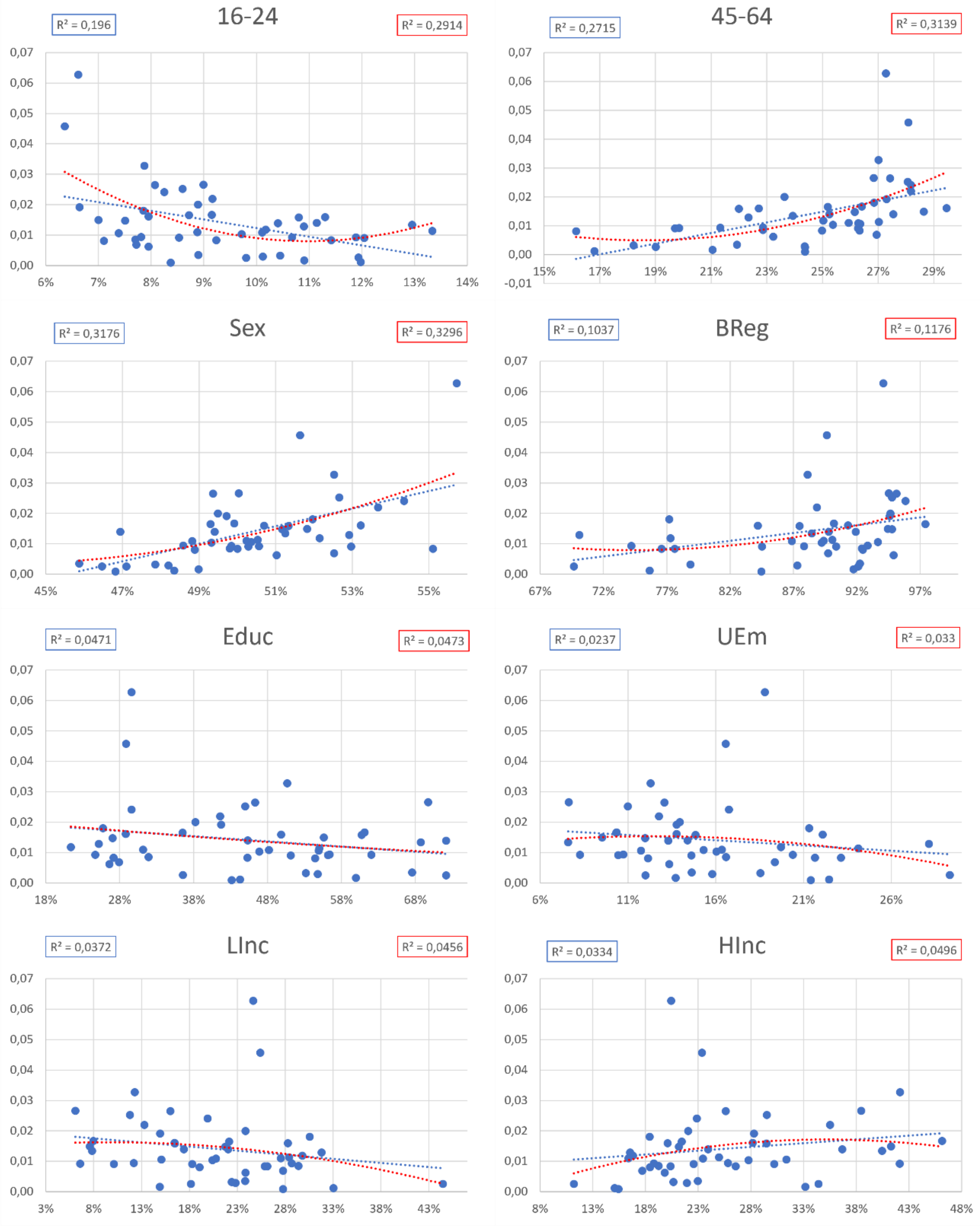

Figure 21: Data points, linear regression model (blue) and polynomial regression model of the second degree (red) along with R-square values for the eight analyzed variables. Installed PV systems per household on the y-axis and unit for each factor on the x-axis.

5.5.2 Solar thermal

Eight out of the 13 analyzed variables chosen for further regression analysis of installed ST systems. The variables are 16-24 years, 45-64 years, sex, birth region, education, unemployment, low economic standard, and high economic standard. A clear negative collinearity (-0.88) was observed for the two ages groups 0-15 years and 65+ years. Since both 0-15 years (-0.16) and 65+ years (0.25) showed a weak correlation with installed ST systems, both were omitted from the regression analysis. No collinearity (-0.65) was observed between the age groups 25-44 years (-0.50) and 45-64 years (0.56). However, since it can be preferable to limit the number of age groups due to compositional data and the groups still showed a clear correlation, the variable with the lowest correlation to installed ST systems (25-44 years) was omitted.

Collinearity was found between birth region and unemployment, but since both these variables are of interest to further analyze, none was omitted. In addition, collinearity was found between average income and: education, unemployment and all economic standard variables. Based on this, and the low correlation (-0.03) between average income and installed ST systems, the variable average income was omitted from further regression analysis. In addition, collinearity was observed between average, low and high economic standard. Average economic standard (0.05) had a moderate correlation to total installed ST systems compared to low (-0.25) and high (0.09) economic standard. It also showed a weak correlation for all municipalities, while both low and high economic standard had at least one moderate correlation. Thus, average economic standard was omitted from further regression analysis. The variable sex showed no collinearity and was further analyzed. As a result, the analyzed variables were the same as for PV systems.

The chosen variables, and data of installed ST systems, were then analyzed through four different forms of regression: linear, polynomial of the second degree, exponential and logarithmic. R-square was used to evaluate the different models to find the type that best fitted the data. As a result, was data points, a linear regression model (orange) and a polynomial regression model of the second degree (green) presented for each of the analyzed variables in Figure 22. R-square for each of the two models are presented in the corners of each plot. The choice of the linear model was based on its simplicity, and the second-degree polynomial regression model showed the highest R-square compared to the exponential and logarithmic model for all analyzed variables. The R-square value for all variables and models is presented in Appendix C.

The polynomial model showed a higher R-square than the linear model for all variables analyzed. The highest R-value (0.51) was observed for the polynomial model of birth region while the lowest R-value (0.01) was found for the linear model of high economic standard. The result is in line with the result presented in the correlation matrix, where birth region has the highest correlation coefficient (0.58) and high economic standard the lowest (0.09). The clearest positive trends were identified for age group 45-64 and birth region, and the clearest negative trend was identified for age group 16-24 years.

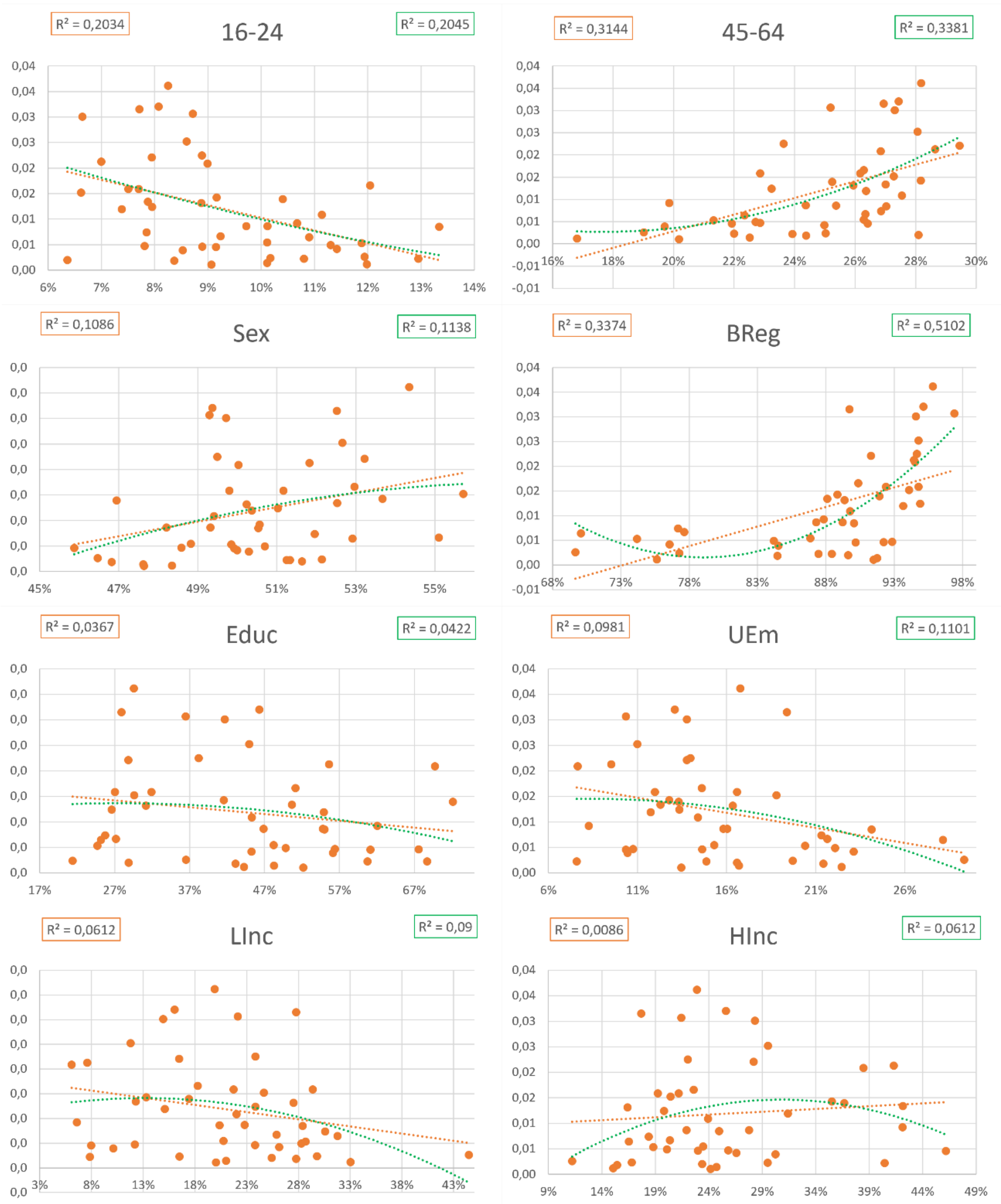

Figure 22: Data points, linear regression model (orange) and polynomial regression model of the second degree (green) along with R-square values for the eight analyzed variables. Installed ST systems per household on the y-axis and unit for each factor on the x-axis.

5.6 Sensitivity analysis

Out of the 53 analyzed DeSO areas, PV systems were identified in 47 DeSOs. In an evaluation of the result in the regression analysis of PV systems, the result for two out of these 47 DeSOs was found to be outliers (0.046-0.063 PV systems per household compared to 0.001-0.033 PV systems per household). Based on this, new correlation coefficients were calculated for the set of 45 DeSOs with the outliers removed. The correlation coefficients for the original 47 DeSOs and the new set of 45 DeSOs is presented in Table 20 for all analyzed demographic variables. The presented values show that the two outliers clearly affecting the result, with all new correlation coefficients different from the original ones. For example, a clearly reduced correlation is found for age group 16-24 years, 65+ years and education. In addition, a clear increased correlation can be identified for unemployment and all variables describing economic conditions.

Table 20: Pearson's correlation coefficient between installed PV systems per household and different demographic factors for (1) all 47 DeSOs with installed systems and (2) 45 DeSOs (outlier DeSOs excluded) with installed systems, in the municipalities Falun, Knivsta and Uppvidinge combined.

Demographic factor	Correlation coefficient for all DeSOs	Correlation coefficient for all DeSOs except outliers
0-15	-0.09	0.06
16-24	-0.44	-0.31
25-44	-0.41	-0.42
45-64	0.52	0.59
65+	0.18	0.00
Sex	0.56	0.50
BReg	0.32	0.36
Educ	-0.22	-0.06
UEm	-0.15	-0.35
AInc	0.00	0.21
EcSt	0.18	0.43
LInc	-0.19	-0.43
HInc	0.18	0.41

Based on the performed regression analysis and differences in correlation coefficients between the original set of DeSOs and the new set of DeSOs, an additional regression analysis was performed for chosen demographic variables. The original regression analysis and the new regression analysis of the 45 DeSOs in the new set are presented in Figure 21 for the variables age group 16-24 years and 45-64 years, unemployment and low economic standard. The result shows a higher R-square for both the new linear and polynomial regression model of the variables age group 45-64 years, unemployment and low economic standard compared to the original models. For age groups 16-24 years, a lower R-square is identified for both regression models in the new analysis, compared to the original analysis.

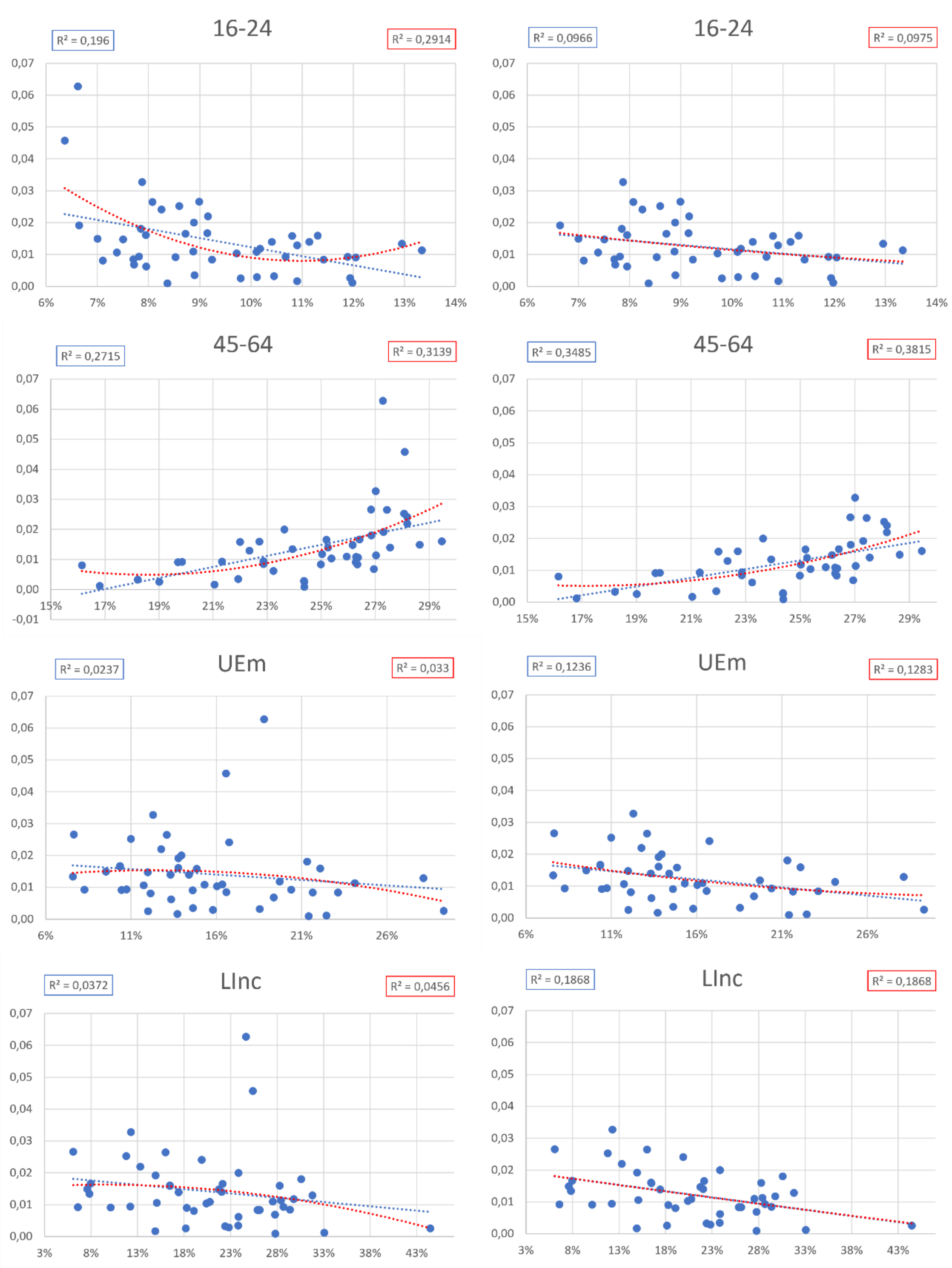

Figure 21: Data points, linear regression model (blue) and polynomial regression model of the second degree (red) along with R-square values for four analyzed variables, the original 47 DeSOs to the left and the new set of 45 DeSOs to the right. Installed PV systems per household on the y-axis and unit for each factor on the x-axis.

6. Discussion

In the Discussion, an evaluation of the chosen methodology and possible alternatives is discussed along with the presented results for PV and ST systems.

6.1 Methodology and assumptions

This section includes a discussion of different choices and assumptions made in the methodology and is divided into three parts: (1) the inventory of solar energy systems, (2) socioeconomic and demographic data and (3) the performed correlation and regression analysis.

6.1.1 Inventory of solar energy systems

This thesis includes an inventory of solar energy systems, and socioeconomic and demographic data connected to these systems. The chosen geographical area for the inventory was limited to three municipalities in Sweden: Falun, Knivsta and Uppvidinge, which were chosen based on available data and characteristics. In a future analysis, other, or a larger number of, municipalities can be analyzed. Especially in a project with a larger scope and time frame. A larger scope can enable a more comprehensive choice and comparison of municipalities, possible with other demand of characteristics, and further, a larger and more complex analysis. An analysis of other municipalities can also, possibly, present a different result compared to this thesis.

The method used in the inventory of solar energy systems can be assumed to be comprehensive. Nevertheless, a more developed version of Afrödull can been more accurate and time effective. A large amount of time was spent on processing suggestions of PV and ST systems presented by the tool, time which can be optimized. However, the amount of identified systems and correct identified systems are connected. A tool which presents a large number of suggestions of systems is less likely to miss systems, but more likely to wrongly identify systems. In this phase in the development of Afrödull, this means more time spent on processing the result, but the aim is that the tool is able to return a highly correct inventory, without requiring time for processing. In this thesis, however, cross-checking with different databases and on-site inspections was performed to complete the inventory. This is assumed to result in the most complete inventory possible, with the tools and registers available.

One clear delimitation of this project is the date of available aerial images, taken during July 2019 in Knivsta and May and June 2020 in Falun and Uppvidinge. It would have been preferable to use photos taken at the same time and at the end of 2020, to match the available socioeconomic and demographic data. These improvements can be beneficial in a future analysis.

The socioeconomic and demographic data used were only available for the year of 2020, including for Knivsta, since this was the only year for which average income could be extracted. As a result, this year was chosen for all municipalities to create a consistency in the result. As previously discussed, a more comprehensive and reliable result can be reached in a future analysis with more precise data. If possible, it can also be interesting to evaluate the deployment of solar energy systems during a period of time, for example a couple of years.

6.1.2 Socioeconomic and demographic data

The levels of analysis, municipality and DeSO, were chosen based on available data and the geographical areas' clear boundaries. An alternative in the future can be to add counties as a level of investigation, which in this thesis would have required a larger inventory of solar energy systems and therefore was not doable. The DeSO level enabled analysis of areas with comparable number of inhabitants, but with different geographical sizes, which showed the differences between different types of areas. This opportunity was interesting, as Balta-Ozkan et. al (2021) found spatial variation in the relationship between PV adoption and investigated variables. Household level was the most aggregated level used, and for some data, the hardest one to define. However, this is not a commonly used or easily accessible level of aggregation. For example, addresses of PV systems were not available for Lukanov and Krieger (2019). This makes it an interesting and unique level of analysis.

The choice of factors for analysis was based on available data and results presented by previous research. Several of the factors, especially at household level, have not been analyzed with such a high granularity earlier. A more advanced analysis can be performed with a larger number of analyzed systems and households, but the retrieval of, especially, average income for households was time consuming in this thesis and therefore not easily applied on a larger analysis material. A future analysis without the limitations in this thesis can investigate the possibility of additional available data, and thus other factors to analyze, which might not have to be socioeconomic and demographic.

In the compilation of the private residential systems set, several assumptions were made. To start with, the owner of each property was assumed to be responsible for the installed systems, even though no insight in the financing was available. The date of the acquisition of the property was either the registration date in the legal registration, or the change of address. For some systems, date of commission of the installation was available to compare with. There are several possible sources of error in this information, from non-existing information about previous owner and lack of or imprecise data. It would have been possible to exclude all systems with possible inaccuracies, but in this thesis, it would have resulted in too few systems to present a relevant analysis. For ST systems for example, no systems would have remained since no information about actual installer of a system was available. In a future analysis, it might be possible to retrieve more specific data.

In addition, the compilation of the owning household can be done differently in a different analysis, if other assumptions regarding the individuals holding the legal registration or living at the same address as the individual holding it, would have been done. If information about the actual, financial responsible, installer of a systems is available, the compilation can be more correct, and enable a more representative analysis. Some systems are justifiably removed, and those remaining in the private residential data are therefore assumed, to the best of our knowledge, to represent the owner and installer of the inventoried solar energy systems.

6.1.3 Correlation and regression analysis

It is possible to express the variables in a different way, which might give a different result. However, the chosen variables are assumed to be relevant in the context. It is also possible to analyze the result in different ways. Nevertheless, due to the scope of the project and based on previous studies, a correlation and regression analysis is a reasonable tool to determined different factors' relation to, and impact on, installed density of solar energy systems.

An alternative to Pearson’s linear correlations coefficient is Spearman’s rank correlation, which analyzes more than linear correlation. For an initial evaluation, however, Pearson’s correlations coefficient is as effective. The chosen definitions of different levels of correlation were initially based on the definition of collinearity. The other levels were chosen to create an evenly distribution of intervals. Of course, the intervals of correlations can be defined in a different way, resulting in a slightly different result.

Correlations coefficients were presented for the complete private residential data set, the municipalities and the different types of DeSO areas. It is possible to also present correlation coefficients for the different types of DeSOs within each municipality, to remove the effect of differences between the municipalities. However, since Uppvidinge only consists of six DeSOs, two of each type, the correlation coefficient would only have the value of -1 or 1, since only two values of each independent variable are considered. Due to this, this result was not presented. As earlier mentioned, the correlations are in some cases weaker due to differences between the municipalities. This could have been considered differently in another analysis of different municipalities, for example.

Based on Pearson’s correlation coefficient some variables were chosen for further evaluation through regression analysis and to create a model fitted to the analyzed data. Several different forms of models were analyzed for each variable, it is, however, possible to evaluate some of the variables combined in a future, more complex, analysis.

In contexts of correlation analysis, it is always important to keep in mind that correlation is not equal to causality. The result in this thesis presents different levels of correlation, but nothing can be said with certainty about causality. In other words, a high correlation is not equal to one of the variables have an influence on the other. In some cases, with correlations between independent variables, it is also hard to distinguish which of the variables influence which, and which one that influence the dependent variable. However, since it is difficult to analyze causality, correlation is a well-functioning tool as long as this fact is kept in mind.

6.2 Results solar photovoltaic

In this section, an evaluation and discussion of the presented result for PV systems is included in five different parts: (1) the different age groups and sex, (2) birth region, (3) education, (4) unemployment and (5) the different economic conditions analyzed.

6.2.1 Different age groups and sex

The result shows an intermediate correlation between installed PV systems and age group 45-64 years for the municipalities combined, which indicates that a population with a higher percentage within this age groups is more likely to install PV systems. The same trend is observed for the municipalities evaluated separately. Bollinger and Gillingham (2012) and Bernards et al. (2018) identified a negative correlation for age group 20-45 years and 25-44 years, respectively, which can be observed in this thesis as well.

However, a (weak) negative correlation is found for age group 0-15 years in the municipalities, both combined and separately, which is not in line with the positive correlation for age group 0-14 years shown by Bernards et al. (2018). In addition, a (weak) positive correlation for age group 65+ years is identified in this thesis, while Bollinger and Gillingham (2012) found lower adoption rates for a large share of the population being over 65 years, and Bernards et al. (2018) found lower adoption rates for a high percentage of the household's members in the age group 75+ years. The presented result in this thesis is thus not in complete line with previous research. However, the analyzed households were relative few, and De Groote et al. (2016) found that household age was less important than previously shown, which might explain, and reduce, the relevance of the identified weak correlation in the opposite direction compared to previous research. In addition, no correlation was shown for age group 65+ years for DeSOs with the outliers excluded in the sensitivity analysis, which is closer to the result presented in previous studies.

The average age in Knivsta is lower (36.9 years) compared to Falun (42.4 years) and Uppvidinge (43.5 years), which might explain the stronger correlation in Knivsta for age groups 0-15 years, 24-44 years and 45-64 years. The regression analysis of age groups 16-24 years and 45-64 years show clear negative and positive trends, respectively. However, there seems to be two DeSO with values that clearly effect the direction. The sensitivity analysis shows, however, that the correlation coefficient without these outliers is lower for age group 16-24 years and higher for age group 45-64 years. The best-fitted model in the original regression analysis is the polynomial of the second degree with a R-value of around 0.3. A value that is not high but slightly increased in the new regression model of age groups 45-64 years and decreased for the new regression model of age groups 16-24 years, in the sensitivity analysis. This might indicate a stronger relation between installed PV systems and percentage in age groups 45-64 years and a weaker relation between installed PV systems and percentage in age group 16-24 years. It can, based on the result, be assumed that the other age groups show similar trends related to their correlation coefficient, especially those with a high negative correlation to the plotted age groups.

The variable sex shows intermediate correlation with installed PV systems (0.56) and age group 45-64 years (0.51), indicating that both a higher percentage of males in this age group and a population with a higher percentage of males are more likely to install PV systems. Bollinger and Gillingham (2012) found that a large share of the population being male was associated with higher adoption rates, while De Groote et al. (2016) analyzed the variable but did not find a significant correlation. In this thesis, the result is inconsistent within the municipalities, with a high positive correlation in Falun (0.66) and Knivsta (0.74), and a negative correlation in Uppvidinge (0.22). Thus, the result can be assumed to be in line with previous research since it indicates that males are more likely to install PV, but a variation resulting in a weak correlation is also found.

The result for the different types of DeSOs might indicate that it is more likely for males to installed PV in *rural area and regional center area* DeSOs, while is seems more likely for females in *urban area* DeSOs. The regression analysis of the variables sex show that a polynomial model of the second degree is the best-fitted model, with a R-value of 0.33. Just as for the age groups, there are three DeSOs analyzed that are outliers, which is affecting the R-value. However, a clear trend is still observed, like the correlation coefficient of the municipalities combined. The compilation of the analyzed households shows a slightly higher percentage of males in these households compared to the municipalities, which also indicates that males are more likely to install PV systems. The largest difference is found in Uppvidinge, might indicating that males living in a rural municipality are more likely to install PV. The fact that the households only consist of members above 20 years, while the municipalities represent the total population, should not significantly affect the result.

6.2.2 Birth region

Pearson's correlation coefficient between birth region and installed PV systems were uncovered to be positive but moderate (0.32). In addition, birth region shows strong negative correlation (-0.75) with unemployment. In the separate evaluation of the municipalities, the result is stronger (0.43-0.87) with a consistent opposite correlation of unemployment. This can indicate that it is not Sweden as birth region per se that increase likelihood of adoption of PV. The result might be due to underlaying factors between the variables, which might indicate that high unemployment means less likelihood of PV adoption, which can be assumed to be reasonable.

The relation between birth region and installed PV have not been analyzed by previous studies presented in this thesis. It might not be directly comparable, but a positive correlation with a high percent of the population being white was identified by Bollinger and Gillingham (2012) and Graziano and Gillingham (2015).

The regression analysis shows a weak trend, with three DeSOs as outliers and a R-value around 0.11 for both models. The majority of DeSOs are centered around 84-96% of the population with Sweden as birth region. This indicates that the result might just be a variation in different shares of the population born outside Sweden in different areas, rather than this groups being less likely to install PV systems.

6.2.3 Education

The variable education shows a weak negative correlation (-0.22) to installed PV systems, and a strong positive correlation to average income (0.76). The municipalities evaluated separately show a negative correlation in Falun and Knivsta and a positive correlation in Uppvidinge. The results for different types of DeSOs show a positive correlation for *urban area* and *regional center area* DeSOs, indicating that a higher education increases the likeliness of installing PV in these areas.

The result presented by Balta-Ozkan et al. (2021) showed a positive correlation between higher education and PV adoption in the analysis overall, but also a spatial variation. The investigated areas with a negative correlation were shown to have a lower level of education, which was assumed to might be an explanation of the result. Thus, the result presented in this thesis is in line with previous research in terms of inconsistency, but contradictory for the overall result. The education correlation for rural area DeSOs is -0.01, and the average education level is lower in rural area DeSOs compared to, for example, regional center area DeSOs in Falun and Knivsta, which, if following Balta-Ozkan (2021), might explain the result. The average education level is more even, and lower, in different DeSO areas in Uppvidinge, which also might explain the positive correlation for the municipality separately.

Lukanov and Krieger (2019) defined the education variable as percent of the population over age 25 with less than a high school education, i.e., a low level of education. The result of their study showed a negative correlation for education, meaning a small percentage of the population with a low level of education correlates with an increased adoption level. Since this thesis defined education as percentage of the population with a higher education, the result presented by Lukanov and Krieger (2019) does corresponds to a positive correlation between education and installed PV systems.

Thus, the overall result (negative correlation between higher education and PV adoption) presented in thesis is not in line with previous research. However, the inconsistent result might be due to different levels of education in different DeSOs, resulting in a disturbed result when combined, especially due to the small sample. This is strengthened by the result of the regression analysis, showing no clear trend but a scattered result. In addition, the result presented in the sensitivity analysis shows that the negative correlation is almost eliminated with outliers removed. A higher education, compared to the neighborhood within a DeSO, seems therefore to slightly increase the likelihood of PV systems, based on the analysis of the municipalities and different DeSO types separately.

6.2.4 Unemployment

Collinearity is found between unemployment and birth region (as mentioned earlier), and all variables describing economic conditions, which seems reasonable. The correlation to installed PV is weak (-0.15) for the municipalities combined, but stronger (-0.16-0.56) when analyzed separately, which exemplifies the different levels of unemployment in the municipalities. Falun and Uppvidinge have an employment rate of 81.6-82.6% while the corresponding value is 87.2% in Knivsta. An evaluating of the result for the different type of DeSOs shows a negative trend in *urban area* DeSOs (-0.52) and *regional center area* DeSOs (-0.35), whilst a weak positive trend (0.08) in *rural area* DeSOs.

Graziano and Gillingham (2015) and De Groote et al. (2016) did not found any significant correlation between unemployment rate and installed PV systems, while Lukanov and Krieger identified a weak negative correlation. Thus, the weak negative correlation presented in this thesis can be assumed to be in line with previous research. However, a difference between different types of DeSOs can be identified. Since the average unemployment rates are similar between the different DeSO types within each municipality, the result indicates that the unemployment rate has a larger influence on adoption of PV systems in *urban area* and *regional center area* DeSOs.

The regression analysis shows that it is difficult to fit a model to the data set, the best one achieved a R-value of 0.03. This might be a result of the different levels of unemployment. Still, there seems to be a small negative trend, with two DeSOs off that might have a negative influence on the fitted models. In fact, the sensitivity analysis shows an increased correlation coefficient with outliers removed, indicating a clearer negative trend.

6.2.5 Economic conditions

All variables show only weak (0.00-0.19) correlation to installed PV, which might be due to the presented variation of average income in the municipalities. This is strengthened by the fact that all variables show stronger correlation in the municipalities separately. Highest correlation is found in Uppvidinge for all variables, which might indicate that income is more important in a rural municipality, or a result of the lower average income, high PV density, or the assumption that higher shares of the population are living in households suitable for PV systems in rural municipalities.

The analysis of different type of DeSOs shows a varied result. A positive correlation is observed for average income, average and high economic standard in *urban area* and *regional center area* DeSOs. An opposite, weak, correlation is found in *rural area* DeSOs. This indicates, unlike previously discussed, that income is less important in rural areas, and that the result presented for Uppvidinge might be due to other factors.

The result presented by Palm (2016) indicates that high income is an explanatory variable for high PV density in Swedish municipalities. In addition, Bollinger and Gillingham (2012), Bernards et al. (2018) and Lukanov and Krieger (2019) found a positive correlation between income and installed PV systems in other areas. This is in line with the positive result presented in this thesis. However, Graziano and Gillingham (2015) and De Groote et al. (2016) found that income is less important and Balta-Ozkan et al. (2021) that income could have a negative influence. These results might explain the varied results identified.

The regression analysis is only performed for low and high economic standard, since these are assumed to best represent the economic conditions. The result shows a clear, but weak, trend in line with previous presented correlations, but with two DeSOs off the trend. In the sensitivity analysis, however, increased correlations are presented for all variables describing economic standard when outlier DeSOs are excluded. None of the originally presented models for the two variables are well-fitted to the data set (R-value of 0.03-0.05). The varied average income in the municipalities and the two DeSOs off might have affected the result. The effect of the two outlier DeSOs is shown in the sensitivity analysis, where the R-value of both models increases with these excluded.

The compilation of analyzed households shows a consistent result with a 25-26% higher average income in households with PV systems compared to the average in each municipality. This trend can also be found when the DeSOs are evaluated separately, with a majority having a positive difference between average income for households and DeSOs. However, as De Groote et al. (2016) stated, wealthier households are more likely to adopt since they are, among other things, more frequently owners of houses that are well suited for PV systems. This might be one thing explaining the differences in income, and in particular, the larger differences in DeSOs of type regional center. An analysis of concentrations of different type of buildings is not included in this thesis, but it can be assumed that there is a higher share of renters in regional centers compared to other areas. If this is the case, and if it is assumed that renters are not included in the wealthiest households in an area, this does explain the result. A positive difference is also found for almost all DeSOs of type rural and urban area, which indicates that the trend, i.e., that high income increasing the likelihood of PV systems, applies for all types of areas.

6.3 Results solar thermal

An evaluation and discussion of the result presented for ST is included in this section, divided into five different parts: (1) the different age groups and sex, (2) birth region, (3) education, (4) unemployment and (5) the different economic conditions analyzed.

6.3.1 Different age groups and sex

A strong correlation to ST systems is not found for any of the age groups, but a positive intermediate correlation (0.56) is found for age group 45-64 years. This might indicate that a higher share of the population within the age group increases the likelihood of installed ST systems. This is in line with the result for PV systems, which is the closest comparison that can be made as there are few previous studies on ST systems.

The result presented for the municipalities separately is more varied. However, a consistent negative correlation for age group 25-44 years and a consistent positive correlation for age group 65+ years are found. No clear trends for all municipalities can be found, except that a population with a high percentage within age group 25-44 is less likely to install ST systems. Beyond this, the result only indicates that there are different trends in different type of municipalities.

Unlike in the correlation analysis, clear trends can be identified in the regression analysis for the two plotted age groups 16-24 years and 45-64 years. The best-fitted model of the latter is the polynomial of the second degree with a R-value of 0.34, and a positive trend is observed, just as for the correlation coefficient. For the age group 16-24 years a clear negative trend is found, but not a well-fitted polynomial model (R-value 0.21). Since this age group shows a positive correlation of 0.32 to age group 25-44 years in the correlation matrix, this result can be assumed to correspond to a negative trend for age group 25-44 years as well. An interesting finding in the evaluation of the compilation of households with ST systems is that the highest average age of the households is found in Falun, which does not have the highest average age of the municipalities. In addition, the longest average time at the residence is found in Uppvidinge, but not the highest average age of the households.

For the variable sex a moderate positive correlation (0.33) to installed ST systems is found. In addition, an intermediate positive correlation (0.52) is found between sex and age group 45-64 years, which indicates that there probably is a high share of males within this age group. This is interesting in a correlation or causality perspective. In addition, it is in line with the result for PV systems.

The regression analysis of the variable sex shows a scattered result, and the R-value of the best-fitted model is only 0.11. It is difficult to identify a trend, which seems reasonable due to the contradictory result presented for the municipalities and type of DeSOs separately. The compilation of the households shows, however, a higher percentage of males in the households with installed ST systems compared to the municipality in general. The investigated households only include members above 20 years, while the municipality takes the whole population into account, but this is assumed to not affect the results.

6.3.2 Birth region

The correlation coefficient between installed ST systems and birth region is 0.58, which corresponds to an intermediate correlation. In addition, birth region shows a correlation of -0.74 to unemployment, indicating that a high percentage of the population with Sweden as birth region correlates to a low percentage unemployed. However, when the municipalities are evaluated separately, the result is more inconsistent. The correlation coefficient is positive for Falun (0.59) and Knivsta (0.45), but negative (-0.19) for Uppvidinge. The previously shown opposite correlation between birth region and unemployment is no longer as clear as it only remains in Falun. In Knivsta the correlation for unemployment is 0.01 and in Uppvidinge -0.17, which is not an opposite correlation to birth region. There is no clear explanation to why this is the case, but the result still indicates that a population with a higher percentage born in Sweden is more likely to adopt ST systems in Falun and Knivsta, but less likely in Uppvidinge.

An evaluation of the regression analysis shows a clear positive trend for a majority of the DeSOs, i.e., DeSOs with 83-98% of the population born in Sweden. There are eight DeSOs with 64-78%, of the population with Sweden as birth region, that are a little off the trend. The linear model has a R-value of 0.34 and the polynomial of the second degree a R-value of 0.51, which are very good results in the context, but it would have been even better without the DeSOs that are off the trend.

6.3.3 Education

Pearson's correlation coefficient between installed ST systems and education is -0.19, which is seen as a weak correlation. The variable education shows, however, positive collinearity with average income. This is assumed to be reasonable since a higher education often results in a higher income. An evaluation of the municipalities separately shows a negative, but stronger (-0.31-0.82), correlation for all municipalities. This indicates that a population with a low percentage high-educated is more likely to install ST systems, which is an interesting trend.

When evaluating the different type of DeSOs a, weak to strong, positive correlation is shown in all different areas. This indicates that high-educated are more likely to install ST systems in all types of DeSOs. However, this thesis does not further analyze different levels of education in different type of DeSOs, and therefore, there might be underlaying factors that are not analyzed. For example, there could be a higher share of high-educated living in urban and regional center areas, which could affect the result. The regression analysis shows a scattered result, a weak negative trend and a R-value of 0.04 for the best-fitted model, which indicates that if there is a trend, it is not strong.

6.3.4 Unemployment

The results presented in the correlation analysis show a moderate negative correlation (-0.31) between unemployment and installed ST systems. In addition, collinearity is found between unemployment and: birth region (-0.74) and average income (-0.70). As previously discussed, underlaying factors between these variables may affect the result of the variables similarly, but in opposite directions, since the correlation is negative. An evaluation of the municipalities separately shows none or a negative correlation, -0.40 for Falun, 0.01 for Knivsta and -0.17 for Uppvidinge. It is possible that the higher employment rate in Knivsta influences the result.

The result for the different DeSOs shows a negative trend for unemployment in all types. The regression analysis shows a scattered result, and the fitted models R-values of 0.10-0.11, which might be an indication that the result achieved for DeSOs of type rural areas in Knivsta is an exception. A weak negative trend can be observed in the regression analysis, especially since the DeSOs with the highest unemployment rate have a low installed amount of PV systems. However, this can still be affected by underlying factors or share of renters for example.

6.3.5 Economic conditions

Pearson’s correlation coefficients between installed ST systems and the economic variables are weak in all cases (0.03-0.25). An evaluation of the municipalities separately shows an inconsistent result for all variables, which together with variation in average income between the municipalities might explain the presented result. The results for the different type of DeSOs are also varied. However, if the expected result would be a positive correlation between installed PV systems and high income, this trend is observed in *urban area* and *regional center area* DeSOs. A more variated and weak result is found in *rural area* DeSOs, which might indicate that a beneficial economic condition is not an explanatory variable in these areas.

The result of the regression analysis shows a very scattered plot for both low and high economic standard and fitted models with R-values of 0.01-0.09. The differences in average income in the municipalities might have affected the result but even with this in mind, it seems hard to identify any clear trends between ST systems and economic conditions. However, when evaluating the analyzed households with ST systems, a clearer trend is found. Households with installed ST systems are shown to have an 13% higher average income than the average in Falun, and 30-32% higher than the average in Knivsta and Uppvidinge. There is a significant larger number of analyzed households in Falun, which might indicate that this is a more representative value.

An evautation of the DeSOs seperately shows that a majority have a positive difference between average income for households with ST systems and DeSOs. The negative differences might, however, depend on a few old and low-income households.

However, De Groote et al. (2016) discussed that wealthier households are more likely to adopt PV systems since they are more likely to own houses suitable for this, which can be assumed to also apply for ST systems. If this is the case, and it is assumed that there is a larger share of renters in regional center areas, it might explain why almost all larger differences are shown in DeSOs of this type. Renters do not typically have the opportunity to install PV systems and, following De Groote et al. (2016) reasoning, usually not the wealthiest households. The difference is positive for almost all DeSOs of type rural and urban areas, which indicates that the trend that households with high income are more likely to install ST systems applies for different types of areas.

7. Conclusions

This section consists of three different parts, each corresponding to one of the three research questions analyzed in this thesis. The first subsection summarizes the inventory of solar energy systems and their locations in terms of areas, properties, and buildings. The second one presents the differences between the analyzed households with solar energy systems and their neighborhood in terms of the socioeconomic factors age, sex, and economic standard, together with some other findings. The last one includes the results of the correlation, regression and sensitivity analysis of the different socioeconomic and demographic variables and installed solar energy systems. It should be noted that there is a difference between the results of the correlation that is analyzed and what conclusions that can be drawn about causality.

7.1 Location of solar energy systems

Of the 692 inventoried PV systems, 43% were installed in rural areas, 12% in urban areas and 44% in regional center areas. There were 16 PV systems installed per 1000 inhabitants in rural areas, 8 in urban areas and 5 in regional center areas. The highest density is found in the rural municipality Uppvidinge for all types of areas. PV systems were installed at single-family dwelling properties in 66% of the cases and agriculture properties in 20% of the cases, and in total were 86% of the properties owned by individuals. The average tax value of the properties was 2 500-5 500 kSEK in the municipalities. In addition, 55% of the PV systems were installed at residential buildings and 36% at complementary buildings.

There were 399 inventoried ST systems, 46% installed in rural areas, 18% in urban areas and 36% in regional center areas. In total, 10 ST systems were installed per 1000 inhabitants in rural areas, 7 in urban areas and 3 in regional center areas. The highest density was found in the large municipality Falun for all types of areas. 72% of the ST systems were installed at single-family dwelling properties and 18% at agriculture properties. The average tax value of the properties was 1 600-3 000 kSEK and 96% of the properties were owned by individuals. ST systems were installed at residential buildings in 77% of the cases and complementary buildings in 21% of the cases.

There is a slightly larger share of ST systems installed in rural and urban areas compared to PV systems. However, the density is comparable in the different types of areas, except a slightly higher density of ST systems in urban areas. The tax value of properties with PV systems is in average higher than properties with ST systems. In addition, it is more common to install PV systems at other types of properties than single-family and agricultural compared to ST systems. Almost all ST systems were installed on residential and agriculture buildings and 9% of the PV systems on other type of buildings. Overall, it is more common for companies to install PV systems, which might explain the different types of properties and buildings, as well as the higher average tax value. The distribution between different types of areas is comparable, with the highest density in rural areas, which most likely is due to the higher share of suitable buildings. The density of PV systems is highest in Uppvidinge and the density of ST systems highest in Falun, displaying differences between different municipalities.

7.2 Households with solar energy systems

The average income of the analyzed households with PV systems is 286-403 kSEK, around 25% higher than the average income in each municipality. The average age of the households (members over 20 years) is 54.4-58.9 years, around 11-13% higher than the average age (inhabitants over 20 years) in each municipality. Specifically, the average age is 54.4-58.9 years for households with PV systems, 5.6-6.1 years higher than the average. The lowest average age of the households is found in Knivsta, which might be due to the lower average age in the municipality. Average time at the residence for households with PV system are 17.1-23.7 years. This shows that the majority have been staying at the residence for a couple of years, which seems reasonable given the higher average age. The percentage of males within households with PV system is 49.9-54.8% compared to 49.6-52.3% in the municipalities.

To summarize the results, the analyzed households with PV systems are shown to be older and with a better economy than the average in the municipalities. However, this may also be a result of the fact that households with a better economy are more likely to live in residences suitable for PV systems. The relative long time at the residences could be explained by both the age of the households, the improved economy over the years and the recent increase of PV systems installations. Nevertheless, a clear difference between households with and without PV systems was found.

The average income of households with ST systems is 372-534 kSEK, which is 13-32% higher than the average income in each municipality. The result is scattered, with a 30-32% difference shown for 23 and 49 analyzed households, and a 13% difference for 287 households. The average age of households with ST systems is 52.3-58.0 years, which is 4-12% higher than the average age in the municipalities, and the largest difference is found in the largest sample of analyzed households. All average ages are calculated for inhabitants over 20 years. The average time at the residence for households with ST systems is 17.8-28.6 years. The percentage of males is 51.4-55.1% in the analyzed households compared to 49.6-52.3% in the municipalities.

The results show that households with ST systems in general have a better economy than the average in the municipalities. Households with installed ST systems are shown to have a 13% higher average income than the average in Falun and 30-32% higher in Knivsta and Uppvidinge. There are a significant larger number of analyzed households in Falun, which might imply that this is a more representative value.

In addition, households with ST systems have a higher average age and a relative long time at the residence. The average age for the households is 52.3-58.0 years, 2.1-6.2 years higher than the average in the municipalities. The lowest average age for the households is found in Knivsta, which probably reflects the lower average age in the municipality. As for PV systems, it is possible that there are other underlying factors that might explain the result. For example, the average time at the residence for the analyzed households is 17.8-28.6 years, which seems reasonable and in line with the higher average age. The difference between households with ST systems and households without ST systems is not as clear as for PV systems, but still noticeable.

7.3 Socioeconomic and demographic variables

The presented result of the correlation analysis shows collinearity and a negative correlation coefficient between age groups 0-15 years and 65+ years, 25-44 years and 45-64 years, indicating that an increase of the percentage of one group corresponds to a decrease of the percentage of the other groups. This result is due to compositional data. There are several variables describing economic conditions in this thesis. Average income and average economic standard (disposable income per consumption unit) represent similar prerequisites, but the latter take different household compositions into account. Average economic standard shows higher correlation than average income, indicating that this variable has a better representation of the economic conditions.

The relation between different socioeconomic and demographic factors and installed PV and ST systems was analyzed through a correlation and regression analysis. Based on the results, including the sensitivity analysis, it can be concluded that variables that have a positive influence on PV adoption are share of the population in age group 45-64 years, share of males, share of the population born in Sweden and a high average income and economic standard. Variables with a negative influence are share of the population within age group 25-44 years, unemployment and low economic standard.

An evaluation of the correlation in different DeSOs indicates that a population with a high percentage within age group 45-64 years is more likely to adopt PV systems in *urban* and *regional area*s, while a high percentage within age group 65+ years is more likely to adopt PV systems in *rural area*s. The result of the different type of DeSOs evaluated separately show an overall positive correlation between percent of the population with Sweden as birth region and installed PV systems. The highest correlation of all economic variables is found in Uppvidinge, which might indicate that income is more important in a rural municipality. It can also be a result of the lower average income, high PV density or the assumption that a higher share of the population is living in households suitable for PV system in rural municipalities.

The result of the correlation analysis of installed ST systems shows collinearity (or intermediate correlation) between several age groups. The analyzed variables describing economic conditions in this thesis represent different aspects of the same prerequisites. Collinearity is therefore expected between the different variables, which also is shown. In addition, several of the economic variables show collinearity with unemployment and a high correlation to education, which seems reasonable.

The correlation and regression analysis of ST systems shows that variables with a positive influence on ST adoption are share of the population within age group 45-64 years and share of the population born in Sweden. A negative correlation is shown for the variables share of population in age group 24-44 years and unemployment.

An evaluation of the result for *urban area* and *regional center area* DeSOs shows a similar result as the previous identified trends in the different municipalities for age groups 25-44 years (negative) and 65+ years (positive). For *rural area* DeSOs, a positive correlation is found for age group 16-24 years. In addition, the result for the different types of DeSOs may indicate that males are more likely to install ST systems in *regional center areas*, while females are more likely in *rural* and *urban areas*. The result for the different types of DeSOs shows a positive correlation between installed ST systems and: birth region and education for all types. A negative trend is found for unemployment in all areas.

References

Balta-Ozkan, N. et al. (2021) ‘Energy transition at local level: Analyzing the role of peer effects and socio-economic factors on UK solar photovoltaic deployment’, Energy Policy, 148, p. 112004. Available at: https://doi.org/10.1016/j.enpol.2020.112004.

Bandaru, S.H. et al. (2021) ‘A Review of Photovoltaic Thermal (PVT) Technology for Residential Applications: Performance Indicators, Progress, and Opportunities’, Energies, 14(13), p. 3853. Available at: https://doi.org/10.3390/en14133853.

Bernards, R., Morren, J. and Slootweg, H. (2018) ‘Development and Implementation of Statistical Models for Estimating Diversified Adoption of Energy Transition Technologies’, IEEE Transactions on Sustainable Energy, 9(4), pp. 1540–1554. Available at: https://doi.org/10.1109/TSTE.2018.2794579.

Bollinger, B. and Gillingham, K. (2012) ‘Peer Effects in the Diffusion of Solar Photovoltaic Panels’, Marketing Science, 31(6), pp. 900–912. Available at: https://doi.org/10.1287/mksc.1120.0727.

Boverket (2012) ‘Utvärdering av solvärmebidraget och solvärmestödet’. Available at: https://www.boverket.se/globalassets/publikationer/dokument/2012/utvardering-av-solvarmebidraget-och-solvarmestodet.pdf.

De Groote, O., Pepermans, G. and Verboven, F. (2016) ‘Heterogeneity in the adoption of photovoltaic systems in Flanders’, Energy Economics, 59, pp. 45–57. Available at: https://doi.org/10.1016/j.eneco.2016.07.008.

Dormann, C.F. et al. (2013) ‘Collinearity: a review of methods to deal with it and a simulation study evaluating their performance’, Ecography, 36(1), pp. 27–46. Available at: https://doi.org/10.1111/j.1600-0587.2012.07348.x.

Energimyndigheten (2021) Solvärme i Sverige — En studie med fokus på potential, ekonomi och bidrag till energi- och klimatmål. Available at: http://www.energimyndigheten.se/nyhetsarkiv/2022/ny-rapport-visar-potentialen-for-storskalig-solvarme-i-fjarrvarmenat (Accessed: 8 August 2022).

Energimyndigheten (2022a) Nätanslutna solcellsanläggningar. Available at: http://www.energimyndigheten.se/statistik/den-officiella-statistiken/statistikprodukter/natanslutna-solcellsanlaggningar/ (Accessed: 8 August 2022).

Energimyndigheten (2022b) Rättigheter och skyldigheter vid anslutning till elnätet. Available at: https://www.energimyndigheten.se/fornybart/solelportalen/vilka-rattigheter-och-skyldigheter-har-jag-vid-installation/dina-rattigheter-och-skyldigheter-vid-anslutning-till-elnatet/ (Accessed: 27 January 2022).

Falu kommun (2021) Kommunfakta. Available at: https://www.falun.se/kommun--demokrati/kommunfakta.html (Accessed: 9 May 2022).

Frisk, E. (2018) ‘Korrelation’, Statistisk ordbok. Statistisk ordbok, 29 August. Available at: https://www.statistiskordbok.se/ord/korrelation/ (Accessed: 15 June 2022).

Graziano, M. and Gillingham, K. (2015) ‘Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment’, Journal of Economic Geography, 15(4), pp. 815–839. Available at: https://doi.org/10.1093/jeg/lbu036.

Hunkin, S. and Krell, K. (2020) ‘Renewable energy selfconsumption - A Policy Brief from the Policy Learning Platform on Low-carbon economy’. Available at: https://www.interregeurope.eu/sites/default/files/inline/Energy_self-consumption__Policy_brief_final.pdf.

Jaxa-Rozen, M. and Trutnevyte, E. (2021) ‘Sources of uncertainty in long-term global scenarios of solar photovoltaic technology’, Nature Climate Change, 11(3), pp. 266–273. Available at: https://doi.org/10.1038/s41558-021-00998-8.

Knivsta kommun (2021) Om Knivsta. Available at: https://knivsta.se/politik-och-organisation/om-knivsta (Accessed: 9 May 2022).

Lantmäteriet (2019a) ‘GSD-Property Map, Vector’.

Lantmäteriet (2019b) ‘Orthophoto’.

Lantmäteriet (2021) ‘Tillhandahållande av Fastighetsinformation’.

Lantmäteriet (2022a) Om Lantmäteriet, Lantmateriet.se. Available at: https://www.lantmateriet.se/sv/Om-Lantmateriet/om-lantmateriet/ (Accessed: 6 May 2022).

Lantmäteriet (2022b) Ordlista, Lantmateriet.se. Available at: https://www.lantmateriet.se/sv/Om-Lantmateriet/Om-oss/Ordlista/ (Accessed: 6 May 2022).

Lantmäteriet (2022c) Vad är ett GIS? Available at: https://www.lantmateriet.se/sv/Om-Lantmateriet/lantmateriet-i-skolan/geoskolan/lektioner-med-gis-for-grundskolan/vad-ar-ett-gis/ (Accessed: 27 January 2022).

Lemaire, X. (2018) ‘Solar home systems and solar lanterns in rural areas of the Global South: What impact?’, WIREs Energy and Environment, 7(5), p. e301. Available at: https://doi.org/10.1002/wene.301.

Lighting Global et al. (2020) ‘Off-grid Solar Market Trends Report March 2020’. International Finance Corporation. Available at: https://www.lightingglobal.org/wp-content/uploads/2020/05/VIVID_OCA_2020_Off_Grid_Solar_Market_Trends_Report_Full_High-compressed.pdf (Accessed: 8 August 2022).

Lindahl, J. et al. (2021) ‘National Survey Report of PV Power Applications in Sweden 2020’. International Energy Agency Photovoltaic Power Systems Programme Technology Collaboration Programme (IEA PVPS). Available at: https://iea-pvps.org/wp-content/uploads/2021/10/National-Survey-Report-of-PV-Power-Applications-in-Sweden-2020.pdf (Accessed: 27 January 2022).

Louvet, Y. et al. (2019) 'Economic comparison of reference solar thermal systems for households in five European countries', Solar Energy, 193, pp. 85–94. Available at: https://doi.org/10.1016/j.solener.2019.09.019.

Lukanov, B.R. and Krieger, E.M. (2019) 'Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California', Energy policy, 134(Journal Article), p. 110935. Available at: https://doi.org/10.1016/j.enpol.2019.110935.

Masson, G. et al. (2021) 'Trends in Photovoltaic applications 2021'. International Energy Agency Photovoltaic Power Systems Programme Technology Collaboration Programme (IEA PVPS). Available at: https://iea-pvps.org/wp-content/uploads/2022/01/IEA-PVPS-Trends-report-2021-4.pdf.

Mayer, K. et al. (2020) 'DeepSolar for Germany: A deep learning framework for PV system mapping from aerial imagery', in 2020 International Conference on Smart Energy Systems and Technologies (SEST). 2020 International Conference on Smart Energy Systems and Technologies (SEST), pp. 1–6. Available at: https://doi.org/10.1109/SEST48500.2020.9203258.

Mills, B.F. and Schleich, J. (2009) 'Profits or preferences? Assessing the adoption of residential solar thermal technologies', Energy Policy, 37(10), pp. 4145–4154. Available at: https://doi.org/10.1016/j.enpol.2009.05.014.

Mu, L. et al. (2021) 'The LCOE Evolution and Grid Parity Analysis of Centralized Solar Photovoltaic: A Case Study of Ningxia, China', Frontiers in Energy Research, 9. Available at: https://doi.org/10.3389/fenrg.2021.711864.

Naturskyddsföreningen (2022) Hur fungerar solceller och solfångare?, Naturskyddsföreningen. Available at: https://www.naturskyddsforeningen.se/faktablad/hur-fungerar-solceller-och-solfangare/ (Accessed: 8 August 2022).

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. Available at: https://doi.org/10.1016/j.erss.2015.12.027.

Palm, A. (2020) 'Early adopters and their motives: Differences between earlier and later adopters of residential solar photovoltaics', Renewable and Sustainable Energy Reviews, 133, p. 110142. Available at: https://doi.org/10.1016/j.rser.2020.110142.

Palm, J. and Tengvard, M. (2011) 'Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden', Sustainability: Science, Practice and Policy, 7(1), pp. 6–15. Available at: https://doi.org/10.1080/15487733.2011.11908061.

Ratsit (2022a) Om Ratsit. Available at: https://www.ratsit.se/info/om-ratsit/ (Accessed: 6 May 2022).

Ratsit (2022b) Ratsitkatalogen 2022 - Sveriges bredaste taxeringskalender. Available at: https://www.ratsit.se (Accessed: 6 May 2022).

Regeringskansliet (2015) Arbetet på lokal nivå, Regeringskansliet. Regeringen och Regeringskansliet. Available at: https://www.regeringen.se/sa-styrs-sverige/arbetet-pa-lokal-niva/ (Accessed: 9 May 2022).

Riksdagsförvaltningen (2021) Förordning (2009:689) om statligt stöd till solceller t.o.m. SFS 2021:855. Available at: https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-2009689-om-statligt-stod-till_sfs-2009-689 (Accessed: 27 January 2022).

RISE (2022) RISE.

Robinson, S.A. and Rai, V. (2015) 'Determinants of spatio-temporal patterns of energy technology adoption: An agent-based modeling approach', Applied Energy, 151, pp. 273–284. Available at: https://doi.org/10.1016/j.apenergy.2015.04.071.

Skatteverket (2022a) Så fungerar skattereduktionen för grön teknik. Available at: https://www.skatteverket.se/privat/fastigheterochbostad/gronteknik/safungerarskattereduktionenforgronteknik.4.676f4884175c97df4192870.html (Accessed: 27 June 2022).

Skatteverket (2022b) Typkoder för fastigheter. Available at: https://skatteverket.se/foretag/skatterochavdrag/fastighet/fastighetstaxering/typkoder.4.3f4496fd14864cc5ac9126d.html (Accessed: 6 May 2022).

Skatteverket (2022c) Typkoder för fastighetstaxering | Skatteverket. Available at: https://www.skatteverket.se/privat/fastigheterochbostad/fastighetstaxering/typkoder.4.2b543913a42158acf800022661.html (Accessed: 6 May 2022).

Statistics Sweden (2018) 'Statistik på ruta från SCB'.

Statistics Sweden (2022a) About Statistics Sweden, Statistiska Centralbyrån. Available at: http://www.scb.se/en/About-us/ (Accessed: 28 April 2022).

Statistics Sweden (2022b) Befolkningens medelålder efter region och år, Statistikdatabasen. Available at: https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101B/BefolkningMedelAlder/table/tableViewLayout1/ (Accessed: 9 May 2022).

Statistics Sweden (2022c) Demografiska statistikområden, en ny regional indelning under kommuner, Statistiska Centralbyrån. Available at: http://www.scb.se/hitta-statistik/artiklar/2018/demografiska-statistikomraden-en-ny-regional-indelning-under-kommuner/ (Accessed: 28 April 2022).

Statistics Sweden (2022d) Folkmängden per region efter födelseregion och kön. År 2010 - 2021, Statistikdatabasen. Available at: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101Y/FolkmDesoLandKonN/ (Accessed: 6 May 2022).

Statistics Sweden (2022e) Kommuner i siffror. Available at: https://kommunsiffror.scb.se/ (Accessed: 9 May 2022).

Statistics Sweden (2022f) Sammanräknad förvärvsinkomst för boende i Sverige den 31/12 resp år efter region, kön, ålder och inkomstklass. År 1991 - 2020, Statistikdatabasen. Available at: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__HE__HE0110__HE0110A/SamForvInk2/ (Accessed: 6 May 2022).

Svenska Kraftnät (2021) Sveriges elnät. Available at: https://www.svk.se/om-kraftsystemet/oversikt-av-kraftsystemet/sveriges-elnat/ (Accessed: 27 January 2022).

Uppvidinge kommun (2022) Kommunfakta. Available at: https://www.uppvidinge.se/kommun-och-politik/kommunfakta.html (Accessed: 9 May 2022).

Weiss, W. and Spörk-Dür, M. (2021) 'Solar Heat Worldwide 2021 Edition'. IEA Solar Heating & Cooling Programme. Available at: https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2021.pdf.

Wikipedia (2022) Knivsta. Available at: https://sv.wikipedia.org/w/index.php?title=Knivsta&oldid=50436473 (Accessed: 9 May 2022).

Wilson, C. et al. (2020) 'Granular technologies to accelerate decarbonization', Science, 368(6486), pp. 36–39. Available at: https://doi.org/10.1126/science.aaz8060.

Woersdorfer, J.S. and Kaus, W. (2011) 'Will nonowners follow pioneer consumers in the adoption of solar thermal systems? Empirical evidence for northwestern Germany', Ecological Economics, 70(12), pp. 2282–2291. Available at: https://doi.org/10.1016/j.ecolecon.2011.04.005.

Appendix A

Table A1: Average income for households with installed PV systems in Falun, average income in the municipality, the difference between these and the number of households with PV systems in the private residential set of Falun

DeSO	Type of DeSO	Average income of households with PV systems	Average income of all households	Difference	Number of households with PV systems
2080A0010	Rural area	420 532 SEK	352 400 SEK	19%	14
2080A0020	Rural area	449 923 SEK	362 400 SEK	24%	21
2080A0030	Rural area	339 590 SEK	337 900 SEK	1%	19
2080A0040	Rural area	333 869 SEK	316 700 SEK	5%	14
2080A0050	Rural area	292 316 SEK	295 100 SEK	-1%	5
2080A0060	Rural area	412 337 SEK	296 100 SEK	39%	33
2080B2010	Urban area	367 675 SEK	305 900 SEK	20%	3
2080B2020	Urban area	410 506 SEK	319 200 SEK	29%	7
2080B3010	Urban area	388 753 SEK	298 000 SEK	30%	8
2080B4010	Urban area	360 295 SEK	307 800 SEK	17%	13
2080B5010	Urban area	380 952 SEK	306 100 SEK	24%	10
2080C1010	Regional Center	353 060 SEK	370 400 SEK	-5%	6
2080C1020	Regional Center	544 561 SEK	346 100 SEK	57%	9
2080C1030	Regional Center	402 692 SEK	363 900 SEK	11%	9
2080C1040	Regional Center	415 690 SEK	338 100 SEK	23%	12
2080C1050	Regional Center	461 023 SEK	399 000 SEK	16%	7
2080C1060	Regional Center	233 300 SEK	296 700 SEK	-21%	1
2080C1070	Regional Center	357 573 SEK	322 100 SEK	11%	13
2080C1080	Regional Center	413 747 SEK	328 800 SEK	26%	2
2080C1090	Regional Center	371 964 SEK	254 800 SEK	46%	2
2080C1100	Regional Center	362 719 SEK	344 900 SEK	5%	6
2080C1110	Regional Center	499 497 SEK	282 900 SEK	77%	1
2080C1120	Regional Center	571 644 SEK	370 900 SEK	54%	8
2080C1130	Regional Center	0 SEK	334 500 SEK	0%	0
2080C1140	Regional Center	0 SEK	298 600 SEK	0%	0

2080C1150	Regional Center	0 SEK	343 900 SEK	0%	0
2080C1160	Regional Center	0 SEK	335 100 SEK	0%	0
2080C1170	Regional Center	330 582 SEK	366 000 SEK	-10%	1
2080C1180	Regional Center	616 367 SEK	409 500 SEK	51%	2
2080C1190	Regional Center	285 935 SEK	346 000 SEK	-17%	3
2080C1200	Regional Center	519 632 SEK	422 400 SEK	23%	14
2080C1210	Regional Center	0 SEK	230 300 SEK	0%	0
2080C1220	Regional Center	604 961 SEK	424 400 SEK	43%	9
2080C1230	Regional Center	361 313 SEK	366 800 SEK	-1%	4
2080C1240	Regional Center	0 SEK	218 700 SEK	0%	0
2080C1250	Regional Center	307 905 SEK	319 100 SEK	-4%	8
2080C1260	Regional Center	403 405 SEK	343 100 SEK	18%	12

Table A2: Average income for households with installed PV systems in Knivsta, average income in the municipality, the difference between these and the number of households with PV systems in the private residential set of Knivsta

DeSO	Type of DeSO	Average income of households with PV systems	Average income of all households	Difference	Number of households with PV systems
0330A0010	Rural area	485 545 SEK	404 900 SEK	20%	22
0330A0020	Rural area	462 448 SEK	393 900 SEK	17%	20
0330A0030	Rural area	397 276 SEK	341 000 SEK	17%	8
0330C1010	Regional Center	504 420 SEK	357 300 SEK	41%	6
0330C1020	Regional Center	459 904 SEK	391 100 SEK	18%	14
0330C1030	Regional Center	879 852 SEK	331 400 SEK	165%	5
0330C1040	Regional Center	622 246 SEK	454 700 SEK	37%	11
0330C1050	Regional Center	616 710 SEK	558 600 SEK	10%	4
0330C1060	Regional Center	494 059 SEK	521 500 SEK	-5%	6
0330C1070	Regional Center	424 992 SEK	415 300 SEK	2%	7

Table A3: Average income for households with installed PV systems in Uppvidinge, average income in the municipality, the difference between these and the number of households with PV systems in the private residential set of Uppvidinge

DeSO	Type of DeSO	Average income of households with PV systems	Average income of all households	Difference	Number of households with PV systems
0760A0010	Rural area	339 808 SEK	275 700 SEK	23%	22
0760A0020	Rural area	356 189 SEK	298 400 SEK	19%	23
0760B2010	Urban area	316 304 SEK	290 100 SEK	9%	10
0760B3010	Urban area	346 802 SEK	292 400 SEK	19%	5
0760C1010	Regional Center	436 766 SEK	275 600 SEK	58%	6
0760C1020	Regional Center	404 881 SEK	290 100 SEK	40%	7

Appendix B

Table B2: Average income for households with installed ST systems in Falun, average income in the municipality, the difference between these and the number of households with ST systems in the private residential set of Falun

DeSO	Type of DeSO	Average income of households with ST systems	Average income of all households	Difference	Number of households with ST systems
2080A0010	Rural area	429 997 SEK	352 400 SEK	22%	22
2080A0020	Rural area	371 019 SEK	362 400 SEK	2%	21
2080A0030	Rural area	353 752 SEK	337 900 SEK	5%	23
2080A0040	Rural area	306 931 SEK	316 700 SEK	-3%	21
2080A0050	Rural area	337 802 SEK	295 100 SEK	14%	23
2080A0060	Rural area	311 422 SEK	296 100 SEK	5%	8
2080B2010	Urban area	377 392 SEK	305 900 SEK	23%	6
2080B2020	Urban area	368 681 SEK	319 200 SEK	16%	13
2080B3010	Urban area	355 267 SEK	298 000 SEK	19%	15
2080B4010	Urban area	320 196 SEK	307 800 SEK	4%	14
2080B5010	Urban area	374 483 SEK	306 100 SEK	22%	12
2080C1010	Regional Center	408 146 SEK	370 400 SEK	10%	5
2080C1020	Regional Center	480 503 SEK	346 100 SEK	39%	7
2080C1030	Regional Center	0 SEK	363 900 SEK	0%	0
2080C1040	Regional Center	333 409 SEK	338 100 SEK	-1%	6
2080C1050	Regional Center	348 652 SEK	399 000 SEK	-13%	10
2080C1060	Regional Center	212 348 SEK	296 700 SEK	-28%	2
2080C1070	Regional Center	403 842 SEK	322 100 SEK	25%	4
2080C1080	Regional Center	438 888 SEK	328 800 SEK	33%	6
2080C1090	Regional Center	383 560 SEK	254 800 SEK	51%	2
2080C1100	Regional Center	472 039 SEK	344 900 SEK	37%	11
2080C1110	Regional Center	320 909 SEK	282 900 SEK	13%	1
2080C1120	Regional Center	435 047 SEK	370 900 SEK	17%	9
2080C1130	Regional Center	212 511 SEK	334 500 SEK	-36%	1
2080C1140	Regional Center	0 SEK	298 600 SEK	0%	0

2080C1150	Regional Center	0 SEK	343 900 SEK	0%	0
2080C1160	Regional Center	436 320 SEK	335 100 SEK	30%	1
2080C1170	Regional Center	0 SEK	366 000 SEK	0%	0
2080C1180	Regional Center	0 SEK	409 500 SEK	0%	0
2080C1190	Regional Center	289 612 SEK	346 000 SEK	-16%	4
2080C1200	Regional Center	480 729 SEK	422 400 SEK	14%	11
2080C1210	Regional Center	0 SEK	230 300 SEK	0%	0
2080C1220	Regional Center	346 281 SEK	424 400 SEK	-18%	9
2080C1230	Regional Center	402 954 SEK	366 800 SEK	10%	2
2080C1240	Regional Center	0 SEK	218 700 SEK	0%	0
2080C1250	Regional Center	337 952 SEK	319 100 SEK	6%	9
2080C1260	Regional Center	444 479 SEK	343 100 SEK	30%	9

Table B2: Average income for households with installed ST systems in Knivsta, average income in the municipality, the difference between these and the number of households with ST systems in the private residential set of Knivsta

DeSO	Type of DeSO	Average income of households with ST systems	Average income of all households	Difference	Number of households with ST systems
0330A0010	Rural area	709 053 SEK	404 900 SEK	75%	9
0330A0020	Rural area	437 501 SEK	393 900 SEK	11%	13
0330A0030	Rural area	321 738 SEK	341 000 SEK	-6%	11
0330C1010	Regional Center	574 455 SEK	357 300 SEK	61%	3
0330C1020	Regional Center	739 424 SEK	391 100 SEK	89%	2
0330C1030	Regional Center	0 SEK	331 400 SEK	0%	0
0330C1040	Regional Center	785 084 SEK	454 700 SEK	73%	3
0330C1050	Regional Center	697 903 SEK	558 600 SEK	25%	4
0330C1060	Regional Center	727 836 SEK	521 500 SEK	40%	1
0330C1070	Regional Center	486 679 SEK	415 300 SEK	17%	3

Table B3: Average income for households with installed ST systems in Uppvidinge, average income in the municipality, the difference between these and the number of households with ST systems in the private residential set of Uppvidinge

DeSO	Type of DeSO	Average income of households with ST systems	Average income of all households	Difference	Number of households with ST systems
0760A0010	Rural area	326 289 SEK	275 700 SEK	18%	9
0760A0020	Rural area	505 062 SEK	298 400 SEK	69%	1
0760B2010	Urban area	261 354 SEK	290 100 SEK	-10%	2
0760B3010	Urban area	415 203 SEK	292 400 SEK	42%	4
0760C1010	Regional Center	441 108 SEK	275 600 SEK	60%	3
0760C1020	Regional Center	398 880 SEK	290 100 SEK	37%	4

Appendix C

Table C1: R-square values for the different regression models for the eight analyzed variables of installed PV systems. The best R-value marked in bold text.

Analyzed variable	R-square linear regression model	R-square (2-deg) polynomial regression model	R-square exponential regression model	R-square logarithmic regression model
16-24 years	0.196	**0.291**	0.241	0.224
45-64 years	0.272	**0.314**	0.309	0.253
Sex	0.318	0.330	**0.341**	0.314
Birth region	0.104	**0.118**	0.114	0.100
Education	0.047	**0.050**	0.047	0.045
Unemployment	0.024	**0.033**	0.019	0.019
Low economic standard	0.037	**0.046**	0.030	0.028
High economic standard	0.028	**0.050**	0.028	0.044

Table C1: R-square values for the different regression models for the eight analyzed variables of installed ST systems. The best R-value marked in bold text.

Analyzed variable	R-square linear regression model	R-square (2-deg) polynomial regression model	R-square exponential regression model	R-square logarithmic regression model
16-24 years	0.203	**0.205**	0.194	0.201
45-64 years	0.314	**0.338**	0.338	0.300
Sex	0.109	**0.114**	0.091	0.110
Birth region	0.337	**0.510**	0.456	0.317
Education	0.037	**0.042**	0.034	0.028
Unemployment	0.098	**0.110**	0.081	0.078
Low economic standard	0.061	**0.09**	0.045	0.035
High economic standard	0.009	**0.061**	0.005	0.018