

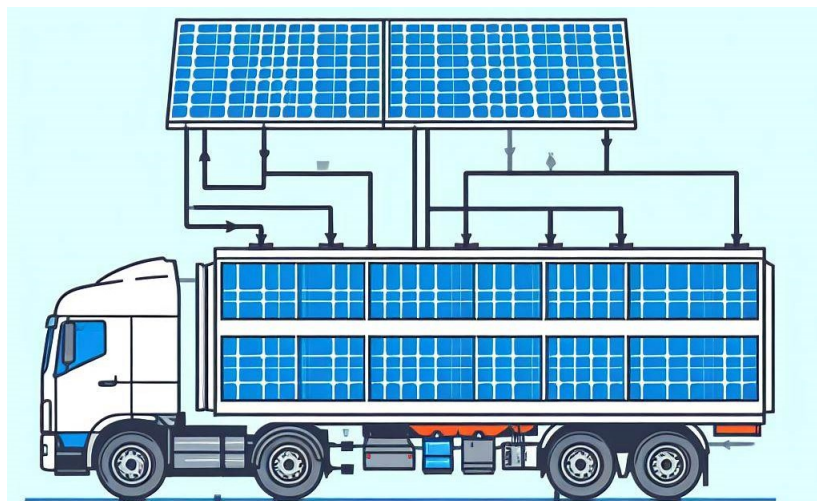
Chalmers University of Technology

SOLAR ENERGY: FROM PHOTONS TO FUTURE SOCIETAL IMPACT, TRA230

SunCare Hub

A Solar-powered Portable Basic Healthcare Facility for Rural Areas

A COMPARISON BETWEEN NORTHERN EUROPE (SWEDEN) AND SOUTHERN EUROPE (SPAIN)



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Abstract

Rural communities are globally faced with depopulation challenges caused by urbanization, jeopardizing their role in preserving national heritage. This case study investigates the feasibility and impacts of the SunCare Hub, a solar-powered mobile healthcare facility in the context of rural areas in Spain and Sweden. The integration of monocrystalline solar panels forms the focal point, with the study undertaking an assessment of technical, social, economic, and environmental aspects.

The technical analysis examines solar panel area requirements, factoring in variables like energy consumption, solar irradiance, and efficiency. Findings indicate fluctuating panel surface needs across seasons, presenting an opportunity for energy backup through battery systems. In Spain, the societal impacts concentrate on mitigating rural depopulation, aligning with Sustainable Development Goals (SDGs) such as Good Health and Well-being (SDG 3) and Sustainable Cities and Communities (SDG 11). The SunCare Hub emerges as a solution to enhance healthcare accessibility, uphold cultural identity, and contribute to the revitalization of rural areas.

In Sweden, the project strategically addresses service inequalities between urban and rural regions, placing a notable emphasis on providing healthcare updates for elderly populations. Environmental considerations include the life cycle of solar panels, battery recycling processes, and solar photovoltaic (PV) recycling. Despite the energy-intensive nature of solar panel manufacturing, the short energy payback time favors their adoption over their extended lifespan. Battery recycling underscores sustainable practices, while PV recycling mitigates material depletion and toxic emissions.

Economically, the study envisions a positive impact on rural repopulation, anticipating favorable outcomes for local economies, employment rates, and industry growth. The SunCare Hub's potential to offer accessible healthcare aligns with socioeconomic benefits, reinforcing SDGs related to Reduced Inequalities (SDG 10). The study highlights the diversity of the SunCare Hub's impact, emphasizing the imperative for holistic planning, further research, and validation to enhance sustainable healthcare solutions tailored for diverse rural communities.

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1 Introduction

Rural communities are present all over the world, and it is easy to always look upon them with a scrutinizing perspective. But these communities are often key-contributors to preservation of national heritages [1]. However there is an ongoing depopulation of rural communities in the wake of the urbanisation and to ensure the possibility for these communities to prosper, the idea is to perform a case study where a solar powered basic healthcare facility is placed within a truck - making it portable.

The idea is to align this case study with the UN's Sustainable Development Goals (SDGs) and the need for a more sustainable society, both locally and globally, to ensure future and current generations prosperity. This project's focus is to investigate a potential way of reducing hurdles for providing good quality, and accessible basic healthcare via an moving solar powered truck. The idea is to deal with the following SDGs [2] and show how each of them are aligning with the SunCare Hub:

- **SDG 3: Good-health & Well-being.** The healthcare truck can serve as a mobile clinic, bringing essential healthcare services, medical screenings, and vaccinations to remote or under-served areas, improving access to healthcare.
- **SDG 7: Affordable & Clean Energy.** The use of solar power in the healthcare truck relates with the goal of promoting clean and sustainable energy sources.
- **SDG 10: Reduced & Inequalities.** The mobile healthcare unit can address health disparities by reaching marginalized or remote communities that may lack access to traditional healthcare facilities.
- **SDG 11: Sustainable Cities & Communities** The healthcare truck supports the development of sustainable communities by addressing healthcare needs in both urban and rural areas. By operating as a mobile unit base based on solar power, it can respond to changing population dynamics and provide healthcare services where they are most needed, contributing to the overall well-being and sustainability of communities.

1.1 Aim and Research Questions

This study aims to assess the possibility of utilizing monocrystalline solar panels to power off-grid basic healthcare trucks intended for deployment in two different European regions, specifically Sweden and Spain. The primary objective is to evaluate the technical feasibility as well as social, economic, and environmental impacts of integrating a mobile healthcare facility powered by solar energy.

The following research questions will be studied:

- Explore the possibility of an integrated set-up of mono-crystalline solar cells into the walls and roof of a truck's trailer.
- Review the potential outcome of such truck, depending on geographical site of implementation.
- What are the environmental, societal, and economical implication of this specific solar PV application.

2 Literature Review

The main focus on this report is to provide a basic understanding of a the possible application of solar PV, hence the technology itself has to be reviewed. This section start out with a basic overview of how the Solar PV is working, how it generates a flow of electrons and hence a power, W, output. Further on in the section the focus will broaden conceptually and end-up in section **2.2.1 Systems Set-up** with a more application specific system.

2.1 Solar PV - A Technological Overview

The general idea of generating electricity from the sun is based on the photovoltaic effect. To get this working it is important to have the right material and device to be able to utilize the photovoltaic effect in order to generate electricity [3].

The two things needed to produce electricity from the sun is, sunlight and a solar cell, of course there are more things needed to connect the solar panel to a circuit, but let's focus on the sunlight first. The sunlight consists of photons [4], which can be seen as energy packages, and correspond to certain wavelengths. These photons can excite electrons in a solar cell, made of semiconducting material, only if the energy supplied is larger than the energy bandgap, E_g , of the material. Semiconductor materials have the ability to switch between having conducting or insulating properties. As will be discussed later on in section **2.1.3 Monocrystalline Solar Cells** silicon is a common semiconducting material used in solar cells. To excite the electron within the silicon crystal structure, the energy needed must be larger than its bandgap ($=1.12$ eV) [5]. This amount of energy needs to be supplied by the sunlight.

When the sunlight strikes the solar cell, there are a number of potential outcomes, the main ones are; it get reflected, transmitted or absorbed [6]. However, it is only the absorbed sunlight that provides the energy needed for electricity generation. As mentioned earlier the absorption of a photon in the semiconductor material, will result in excited electrons and are able to be utilized to get useful energy. This phenomena is the photovoltaic effect and is exemplified in Figure 1.

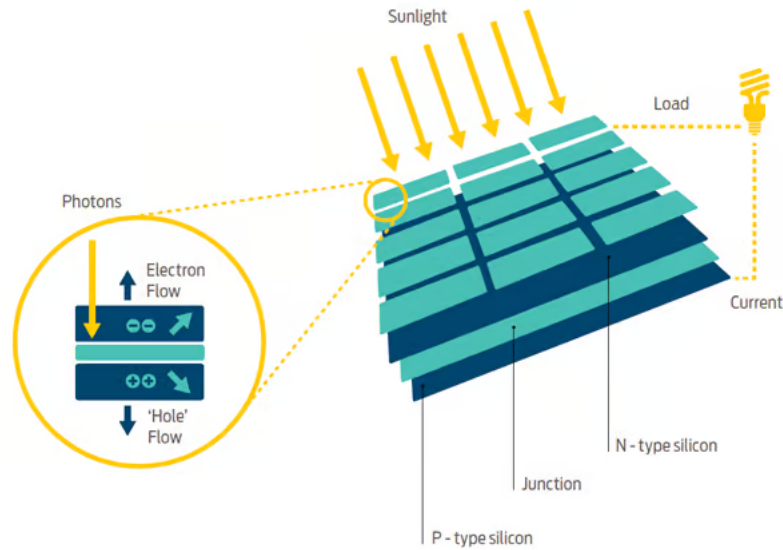


Figure 1: Photovoltaic effect, where it is shown how the sunlight by exciting electrons give rise to a current [7].

In Figure 1 the photoelectric effect is viewed, and in the magnified view of the solar cell the rise of electron movement due to excitation is shown.

To summarize the concepts discussed this far; light hits the semiconducting material where electrons are excited by a photon of the right wavelength. By introducing an external circuit with a load, electricity will be created, this process is repeating itself all the time, the electrons will leave to the external circuit and end-up where they started.

Going from the semiconducting material and how sunlight allows motion of electrons into how a solar panel is set-up. To start there is the *solar cell*, also known as a PV cell, which is where conversion of sunlight into electrical energy by utilizing the photovoltaic effect, generating an electric current [8]. These cells are series connected to increase the overall voltage while having a constant current, hence boosting the power of each *solar panel*, group of connected cells. This configuration enables applications that need higher voltage levels than that of a single cell, for example charging a cellphone.

The solar cell have a DC voltage output of about 0.5 V [9], and by series connecting the cells into a panel the voltage output end up in the range of 12-24 V [10]. The panels are themselves connected into *solar arrays*. All to add up the voltage, and enable grid connection an inverter is needed to convert the solar cell generated DC voltage into the AC voltage used in most appliances [8].

These setups are commonly called *PV modules* and their power is measured under standard test conditions (STC) [10], which will give the *peak watts* (W_p). However the actual power output may differ just by changing geographical location, since during STC the solar irradiance is perpendicular and 1000 W/m^2 among other things [11]. In other words depending on where on earth the angle between the solar rays and the panel may vary, hence decreasing the power output. Other factors decreasing energy output is shading, ambient temperature, and how clean the panels protective glass enclosing is [8].

2.1.1 Effect of Solar Irradiation

A parameter that can change the performance of a solar PV module is the solar irradiance. Solar irradiance is defined as the surface power density, W/m^2 , received from the sun in the form of electromagnetic radiation. The amount of received solar irradiation will vary with the season as well as the geographical location on the earth, hence different countries receive different irradiation. Because the poles of the earth are angled more away from the sun than the tropics, hence the poles receive less solar irradiance on an annual average than the equator. Consequently, the generated power from an installed solar PV module can perform differently [12], depending on where it is installed.

2.1.2 Effect of Temperature

Like all other semiconductor devices, solar cells are sensitive to temperature, which can ultimately affect the solar cell power output. As the temperature increases, the bandgap in the semiconductor will be effectively decreased, thereby altering most of the semiconductor material parameters. In a solar cell, the most affected parameter by an increased temperature is the open-circuit voltage, V_{oc} . The V_{oc} decreases with temperature because of the temperature dependence of I_0 from the diode equation [13]. We can see the dependence of temperature in the IV and PV curves in Figures 2a and 2b respectively.

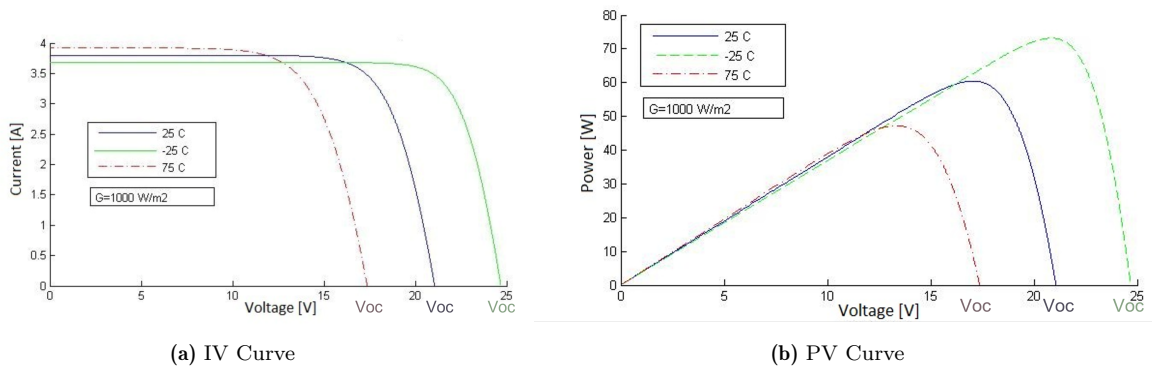


Figure 2: Temperature dependence on V_{oc} and Power [14]

When all parameters are constant, the higher the temperature, the lower the V_{oc} . As a result, from the power equation $P = IV$, a power loss will be experienced. However, if the temperature decreases with respect to the original conditions, the PV output shows an increase in voltage and power. Regarding having solar PV operating in different climates with varying ambient temperatures, solar PV can be more efficient in colder climates with temperatures below STC as the PV system experiences fewer electrical losses resulting in a higher overall efficiency.

2.1.3 Monocrystalline Solar Cells

Silicon stands as the predominant semiconductor material for PV applications. Silicon dioxide (SiO_2) is the most abundant material in the Earth's crust, and 90 % of the current solar cells are made of silicon [5].

In this report, we are only focusing on monocrystalline, or single-crystal silicon (sc-Si). As the name implies, the entire volume of the cell is a single crystal of silicon. The motivation

behind this choice is due to the higher recorded efficiency of this type of solar cell compared to other similar solar cells made from polycrystalline solar cells or thin films. Because of the more ordered ideal structure of the single crystal structure, crystalline silicon exhibits a well-defined band structure, with more space for the electrons to generate a flow of current. This increases efficiency as it achieves a more uniform behavior. Additionally, due to its black color, the absorption of photons increases compared to the blue polycrystalline silicon. The sc-Si has an efficiency range of 15-24%. However, because of the more slow and complex manufacturing process required, it is also the most expensive type of silicon solar cell [15].

2.2 Off-grid Systems

The term "off-grid" is quite an explanatory way of referring to systems or setups that operate independently from the conventional power grid, relying on self-generated and stored energy sources such as solar, wind, or hydro power [16]. Even though developing a solar off-grid system requires high initial costs — the purchase of solar panels, batteries, and an inverter among others, as well as the installation cost of the system — it eventually pays off since the expected lifespan of monocrystalline solar panels is currently between 25 to 30 years [17]. Moreover, in some occasions, it is either impractical or more expensive to extend power lines to remote locations than setting up an off-grid system. Certainly, the suitability of an off-grid system depends on factors such as location, energy needs, and the availability of renewable resources. This is why typical applications of off-grid systems are very specific. Some applications are:

1. **Electrification of homes, schools or healthcare facilities in rural or remote areas.** This is the main application that comes to mind when someone talks about off-grid energy. People living in rural or remote locations have the same right to energy access as those in big cities. It is a fact that setting up all the infrastructure needed to be powered on-grid—like transmission lines, distribution lines, and electrical substations—is substantially more expensive than setting up a solar off-grid system where weather and sunlight are optimal. Therefore, off-grid systems are the best alternative to conventional power in these situations.
2. **Residential sector.** Property owners seek energy self-sufficiency as this lowers one's electricity bill. Aiming for a reduced carbon footprint is another reason that contributes to adopting solar energy instead of relying on utility companies for energy supply. Residential areas with self-sufficient energy systems also offer resilience in the face of power outages and grid failures, guaranteeing a continuous power supply [16].
3. **Emergency power supply in case of natural disasters.** Portable solar off-grid systems are a solution to power outages in areas affected by natural disasters. This can help establish communication in the affected area, ensure water supply, and provide lighting where needed.
4. **Mobile Solar Systems for land expeditions, camping and hiking.** Integrating solar panels on the rooftop of a camper van or even having a solar awning is currently available in the market [18]. Solar energy can be used to power appliances such as lights, refrigerators, and small electronic devices. It can also serve to charge smartphones, laptops, or cameras (generally personal devices).

2.2.1 Systems Set-up

Every solar off-grid system generally consists of the same few components, reducing the complexity of the setup. Having fewer components minimizes complications during installation and maintenance. Additionally, since the energy output depends on the number of solar panels in the system, panels can be added in modules, providing scalability. Modularity is crucial for adjusting the system size to meet energy needs. However, it is not always feasible to add as many panels as desired, as the physical space of the off-grid application may be limited.

Focusing on our solar-powered portable health-care facility, we will detail the key components, their interconnections, and how each contributes to the system’s functionality. In Figure 3, a schematic of our off-grid system is presented.”

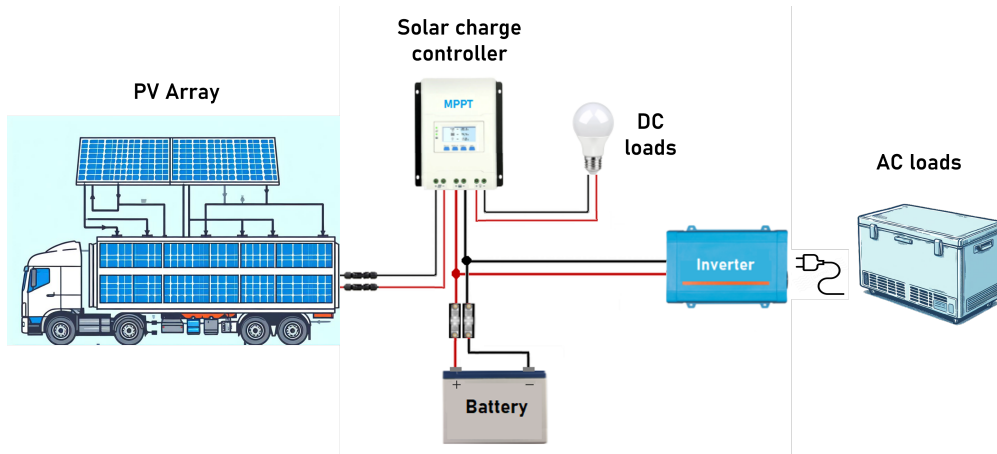


Figure 3: Electrical setup of the solar-powered portable health-care facility

The way the system is assembled electrically is the following:

1. **PV array.** It functions as the primary energy source by capturing sunlight and converting it to electrical energy.
2. **Solar charge controller.** This component regulates the flow of electricity from the PV panels to the batteries, preventing overcharging. It controls the charging voltage and current using a Maximum Power Point Tracker (MPPT). The MPPT accelerates solar charging by comparing the PV output voltage with the battery voltage, adjusting the voltage to obtain the maximum current into the battery [19].

Because temperature significantly affects the power generated from a PV array, using a solar charge controller becomes essential. The MPPT helps batteries recharge efficiently by utilizing the voltage and current that yield maximum power (V_{mp} , I_{mp}), as shown in Figure 4.

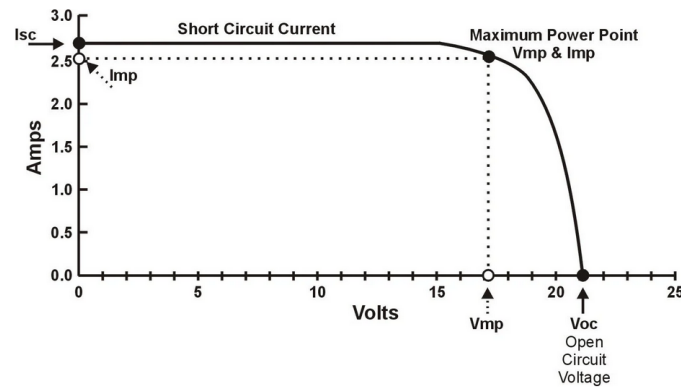


Figure 4: MPPT of a Solar charge controller [20]

3. **Batteries.** The purpose of the batteries is to store the excess electricity generated by the PV panels during the daytime and utilize this stored energy during periods of low sunlight. The absence of sunlight can occur due to cloudy days, nighttime, or when solar panels malfunction or require maintenance. Having batteries serves as an energy backup, ensuring powering to the system during low sunlight periods.
4. **DC loads.** These are devices or appliances that run on DC current. Although we currently do not anticipate using any DC devices in our system, we will keep the possibility open in case any is needed.
5. **Inverter.** An inverter is a necessary device in any system if you want to power AC devices. It converts the energy stored in batteries from DC to AC current, providing power to AC appliances.
6. **AC loads.** In our system, we will power a commercial refrigerator by converting the DC current generated from the PVs and the batteries to AC current. It's possible that more devices or appliances powered by AC current may be needed inside the truck.

3 Case Study

To estimate the required number of solar panels for the SunCare Hub to fulfill a projected power consumption scenario Equation (1) was used.

$$\text{Required panel area (m}^2\text{)} = \frac{\text{Energy Consumption (Wh/day)}}{\text{Solar irradiance (Wh/m}^2\text{-day)} \cdot \text{Efficiency (\%)}} \quad (1)$$

Here, the Required panel area represents the surface area of solar panels needed to meet the energy demand. *Energy Consumption* is an estimation of the daily energy demand anticipated by the SunCare Hub. *Solar Irradiance* denotes the available sunlight, and the *Efficiency* is specific for the chosen solarpanel.

In this case study, the efficiency and energy consumption will be kept the same for the two cases; Sweden and Spain. The two major differences are the Solar irradiance and the number of hours of sunlight hours per day for the two chosen locations. The energy consumption and efficiency in Equation (1) remains unchanged for both cases since the same solar panels and energy consuming equipment will be set constant as a general assumption to limit the variables.

3.1 The SunCare Hub

The SunCare Hub, designed as a mobile unit - a truck, intended to provide basic healthcare services in remote rural regions. The concept involves integrating monocrystalline solar panels together with a battery to meet the electricity demand to power necessary healthcare services within the truck. The intention is to assist the local population by introducing a more accessible healthcare to the population of rural areas. The general idea was already mentioned in section 2.2.1, where an illustrative figure (Figure 3) shows the proposed set up.

The first seasonal estimates was performed by using Equation (1) and plugging in the following assumptions;

- **Efficiency** - 20%.
- **Energy requirement** - 19.2 kWh/day.
- **Daily average solar irradiance** - constant throughout each season.

The first assumption is based upon findings from different monocrystalline solar cells available on the market, e.g., found on various websites with efficiencies around 20 %.

The other assumption is a guesstimate of how much power the SunCare Hub would consume on a daily basis, to ensure regular operation of fridge, and auxiliary equipment.

The last assumption, that the daily average solar irradiance is constant throughout each season was done to ease the grasp of data collection needed. The risk of this to over-/underestimate the amount of available solar resource have been considered and will be discussed later on in the report. The values of solar irradiance used in the calculations are presented in Table 1.

Table 1: Calculated solar irradiance seasonal averages for Castilla La Mancha and Kiruna.

Time of Year	Solar irradiance (Spa) ¹ [Wh/(day-m ²)]	Solar irradiance (Swe) ² [Wh/(day-m ²)]
Winter	3672	100
Spring	5332	3766
Summer	8511	8000
Fall	4165	2233

¹ Averaged Global Irradiance values from J. Polo [21].

² Averaged Global Irradiance values from SMHI summary [22].

In Table 1 it is interesting to see that the solar irradiance for Kiruna is close to zero during the winter period, and almost the same as in Spain during the summer. Moreover, the number of hours with sun in Kiruna during the summer is close to 18 h per day, but zero during a few winter weeks. So during the spring, summer, and fall a battery could ensure day-to-day energy backup, whereas for the winter some other solution would be needed. The authors, have used the following separation of the months;

- **Winter** - December, January, and February.
- **Spring** - March, April, and May.
- **Summer** - June, July, and August.
- **Fall** - September, October, and November.

By using the data presented in Table 1 and plugging it into Equation (1) the required solar panel area was calculated and the results are presented in Table 2.

Table 2: Calculated required solar panel for the SunCare Hub, for both Spain and Sweden and during all four seasons.

Time of Year	Solar panel area (Spain) [m ²]	Solar panel area (Sweden) [m ²]
Winter	26	960
Spring	18	25
Summer	11	12
Fall	23	43

In Table 2 it can be seen that the surface area of solar panels in Spain is varying between 11 – 26 m² depending on the season. The values used for the solar irradiance is for the region Castilla La Mancha [21]. Whereas the value for Sweden varies quite substantially between 12 – 960 m², which is heavily dependent on the chosen location of Abisko with solar irradiance values taken from the city of Kiruna [22], the closest cite with annual measured values found. All values used for both Spain and Sweden are averages of the solar irradiance during the seasons. There will be days with very low irradiance and hence there will be days where the required area is not enough to ensure the power supply to the equipment some energy storage. For this situation, batteries would then be desirable. Moreover, it would be wise to install more capacity than required since this would allow to meet the demand even when the solar conditions are less than peak conditions.

To better understand this and give some context to the values, a truck with the following dimensions (height-length-width) 3-8-2.5 m is used as reference. Adding all sides, its giving a total of 71.5 m² available for solar installation. Together with the previously mentioned risk of overestimating the solar capacity for some days of the seasons, hence underestimating the actual solar panel area needed. The idea is to oversize the panel coverage using all 71.5 m² available, increasing the possibility of meeting the SunCare Hub’s daily energy demand.

Also worth mentioning is that during the ”Winter” period in Abisko the value is quite unrealistic since it is Polar night, when the sun never rises [23], hence the needed solar panels would need to be infinitely large. Thereby, for the the period of Polar nights the SunCare Hub would be of no use, if not charged on-grid utilizing a plug-in solution or a power storage concept, e.g., hydrogen or large batteries. Equation (1) can be rearranged to get Equation (2)

$$\text{Potential solar resource (kWh/day)} = \frac{\text{Solar irradiance (Wh/m}^2\text{-day)} \cdot \text{Efficiency (\%)}}{1000 \text{ (Wh/kWh)} \cdot \text{Available Area}^{-1} \text{ (m}^{-2}\text{)}} \quad (2)$$

where the irradiance data is found in Table 1 and the available area is 71.5 m² from the previous explanation of the assumed truck dimensions, and the efficiency is the assumed 20%. The results from this is presented in Table 3.

Table 3: Calculated solar capacity for a truck with 71.5 m² available for solar panels, seasonal averages for Castilla La Mancha and Kiruna.

Time of Year	Solar capacity (Spa) (kWh/day)	Solar capacity (Swe) (kWh/day)
Winter	53	1
Spring	76	54
Summer	122	114
Fall	60	32

In Table 3 the average available solar capacity is presented and is found to be much greater than the estimated energy demand of 19.2 kWh/day, for all seasons except the winter in Sweden. The main take away with this is that an introduction of a battery to the system is a necessity. The battery load is not included in the assumed consumption of 19.2 kWh/day, but since the majority of the seasons can sustain a energy supply almost a factor two or greater of the assumed demand, it would be no problem of charging a battery and increasing the demand.

Another possible load to add is a battery not used for storage but potentially propulsion of the entire truck. This have not been a main focus of the case study but could be possible during the seasons with high solar irradiance, with a remark of the charging being spread out during multiple days. Either in combination with a regular plug-in solution or as a stand-alone solution if the truck is to be in one place for an extended period of time. A brief investigation on this showed that an electric truck from Scania is equipped with a 412 kWh battery [24]. This battery could ideally be fully charged in four days during the Spanish summer while still providing the constant daily demand of 19.2 kWh.

3.2 Societal Impact

In this section the Societal Impact of the SunCare Hub will be presented for both Spain and Sweden, both countries experiencing a general population decline in rural communities.

3.2.1 Societal Impact - Spain

In Spain, there is an ongoing and significant debate revolving the issue of rural depopulation. The country's population tends to concentrate in large, well-connected cities, such as Madrid, Barcelona, Valencia, and Seville [25], where essential services like healthcare, education, transportation, and infrastructure are readily available. This urban concentration also draws both national and international companies, further contributing to urbanization of these major cities. Consequently, many workers choose to settle in these urban centers, leading to an aging population in rural areas.

The concentration of people in major cities results in increased investments from both the state and autonomous regions, channeling more funds and resources into these urban centers. Unfortunately, this leaves rural Spain with limited means and resources. Despite rural areas comprising 16% of the total population, they cover a vast 84% of the national territory [26]. The population density map in Figure 5 depicts the distribution of Spain's population across its territory as of 2019.

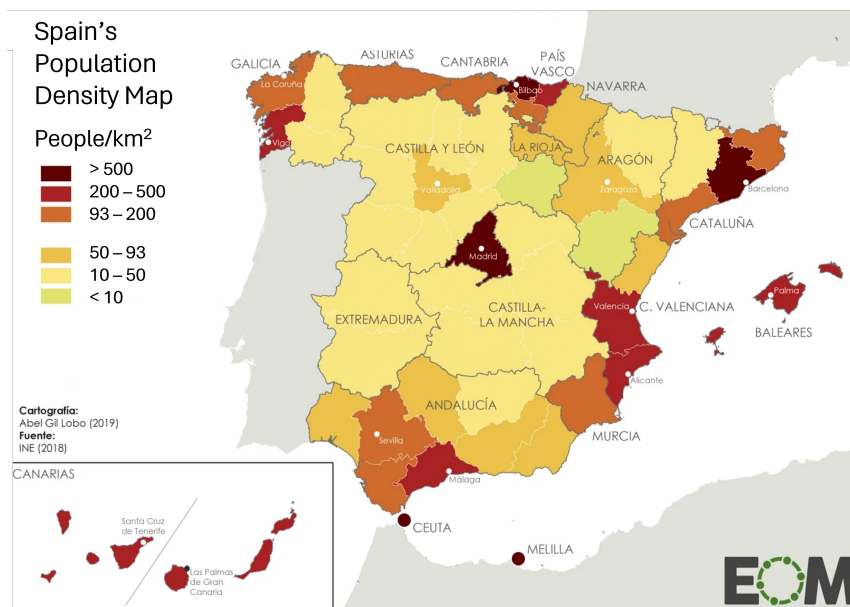


Figure 5: Spain's population density map, 2019 [27]

That is why there has been a recent debate pushing for the same services and infrastructure in rural areas as for the rest of the country. The argument is straightforward—they have the same rights as any other Spaniard to quality healthcare and education, connecting back to SDG 10. To counter rural depopulation, there are proposals for measures to ensure basic services like healthcare and education.

This is where SunCare Hub comes into play. Our solar-powered portable basic healthcare facility

for rural areas aims to complement these measures in the fight against depopulation. Given that Spain has high solar irradiance radiation compared to Northern Europe, approximately 5.2 kWh/m^2 of average daily annual solar irradiation on a horizontal surface [28], an off-grid application can play a crucial role in ensuring adequate healthcare in challenging-to-reach areas, given their demographic and geographical characteristics, particularly in Primary Care. Given that rural populations tend to be older, a portable healthcare facility moving from village to village could sustainably provide the elderly with medicines, vaccines, and other health needs (SDG 3 and 11). Moreover, depopulation often means a loss of cultural identity and local traditions. Implementing the SunCare Hub in Spanish rural areas not only enhances healthcare access but also encourages families to consider rural living. Consequently, this helps maintain and revitalize rural communities, preserving a rich cultural heritage, and prevents the loss of traditional practices.

3.2.2 Societal Impact - Sweden

Similar to Spain, Sweden faces an ongoing debate over equal services and infrastructure in rural areas compared to cities [29]. Figure 6 provides a snapshot of Sweden's population density, highlighting that the most populated regions cluster around major cities like Stockholm, Göteborg, and Malmö.

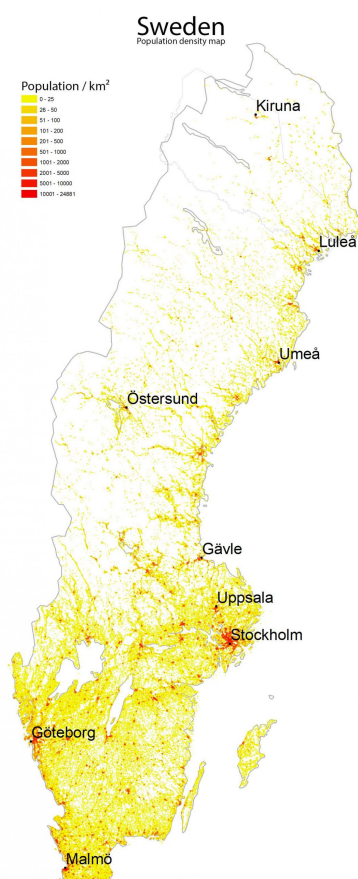


Figure 6: Population density of Sweden in 2019 [30]

In Figure 6 it can be seen there's a noticeable population gradient, both South-North and towards the Swedish Inland, with fewer people in the North and inland. Notably, the average age is higher in Northern municipalities, exceeding that in other parts of Sweden [31].

This age distribution is further illustrated in Figure 7, where the average age in Swedish municipalities is depicted.

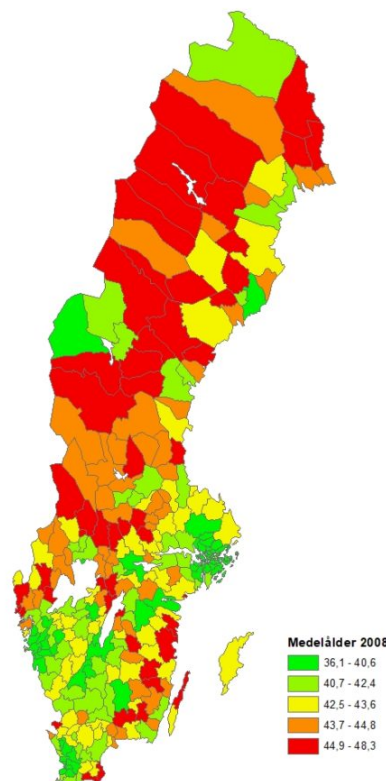


Figure 7: Average age in Swedish municipalities [31], the color red indicates higher and green a lower average age.

The higher average age in the Northern parts of the Swedish Inland seen in Figure 7, coupled with low population density over extensive areas, presents challenges for locals in need of healthcare services [32]. Due to longer travel distances and difficulties in competence acquisition in these regions, ensuring quality care becomes challenging [32]. If implemented, the SunCare Hub could address these challenges by visiting rural communities regularly, providing health updates, especially for the elderly who may face difficulties with digital healthcare solutions [33].

A significant advantage of the SunCare Hub lies in its potential to eliminate the inequality of inaccessible healthcare in rural areas. Moreover, by harnessing clean solar energy, it contributes to the sustainability of the healthcare sector. Depending on the location, the SunCare Hub could replace energy sources such as hydro-power dominant in Northern Sweden or coal, which

is still prevalent in other parts of the world.

3.3 Environmental Impact

In this section the environmental impact of the SunCare Hub will be presented for both Sweden and Spain. There are no major differences in the ways the technological application would differ in the two geographical locations and it is therefore a broader and more general accounting of the environmental aspects of the SunCare Hub that will be presented hereafter.

While the primary motivation behind implementing a portable, solar-powered healthcare facility is its minimal environmental impact, it is crucial to consider all potential sources of pollution that the truck may introduce to the environment:

- **Solar panels manufacturing.** The production of monocrystalline solar panels demands a substantial amount of energy and involves the use of hazardous chemicals like silicon tetrachloride. The manufacturing process begins with the extraction of silica, which despite its abundance, is an energy-intensive undertaking [34] and the process of mining generates greenhouse emissions and can lead to soil, water and air pollution. However, the energy payback time which is the period required for the panel to generate an equivalent amount of energy to that consumed during its production for these panels is usually around 1-2 years [34] which is a really low time compared to the lifespan of a monocrystalline solar panel 25-30 years.
- **Batteries.** Since batteries are necessary to power the medicine refrigerator and medical appliances during cloudy days and nighttime, we have to consider the environmental impact of the recycling process of lithium-ion batteries. When the lifetime of lithium-ion batteries comes to an end (10-20 years) [35] they have to undergo either pyrometallurgical or hydrometallurgical processes. As for now, it is not possible to recover lithium from industrial processes but these processes are able to recover cobalt, nickel, and copper instead. Pyrometallurgy involves carrying out incineration, roasting, and smelting to recover the metals from the batteries whereas hydrometallurgy is the application of aqueous solution to recover metal from ores. The pyrometallurgical procedure, in particular, demands substantial energy input and incorporates gas treatment processes designed to yield reduced quantities of gas byproducts which affects negatively to the environment [36].
- **Recycling of solar PV.** A crystalline-silicon solar panel comprises materials such as silver, aluminum, glass, copper, and silicon [37]. Recycling end-of-life (EoL) panels offers several key benefits, including reducing material depletion, particularly of precious metals like silver. It also plays a crucial role in preventing the release of toxic emissions such as lead and fluorine into the environment. Furthermore, recycling helps avoid the energy expenditure required to produce new materials to replace those in the panels. The process generates economic gains by recovering valuable materials like aluminum, copper, high-purity silicon, and silver. However, it is vital to handle the waste from solar panels carefully when they reach their EoL. Poorly managed EoL solar PV panels can have a negative impact on the environment and human health [38].

Finally, the shift towards renewable energy is a key step to make a major positive impact on the planet. Needless to say, having solar energy replacing the currently fossil fuel dependency in energy production is aligning with SDG 7, ensuring a reduction of carbon emissions from the healthcare sector.

3.4 Economical Impact

In this section the Economic impact of implementing the SunCare Hub will be presented in a more general view for both countries but references are specified for Spain and Sweden.

As explained in the Social impact section, implementing a portable healthcare facility is a measure to prevent depopulation. This is not only a measure to prevent depopulation but a measure to encourage citizens to switch to rural areas instead and repopulate these areas slowly in time. Rural re-population will definitely impact positively the local economy of these villages by:

- **Re-population of rural areas.** Due to more people choosing to stay in rural areas thanks to improved healthcare, this could lead to a positive effect on the economy. The establishment of new industries can positively impact the local and regional economy as well as the employment rate in the area [39]. This giving the local municipalities more tax-money resulting in a positive feedback loop, where by having people move to rural areas they become less poor, making it possible to invest in public services e.g., schools and libraries, making it more attractive for people to stay. Which in turn makes the rural areas more resilient economically since the share of population in working age can increase, instead of decline which can be seen in many places today [31].

Specifically in Spain, in these rural areas, it is common for jobs to be oriented towards agriculture and livestock. Therefore, promoting the repopulation of rural areas can undoubtedly be of great help to these sectors as there is a shortage of labor for certain tasks. Also, in the case of migrations from cities to villages, local businesses such as bakeries, butchers, and other everyday shops would be needed. Adding all of this together would help to reactivate the local economy of villages that are in the process of disappearing.

- **Socioeconomic benefits.** The possibility of accessible healthcare can ensure earlier diagnosis, which in return can result in a more cost effective health-system. This with idea of early detection having the potential of faster and potentially full recovery. And this can lower the public spending's on advanced and extensive treatments, since a early detected issue can most times be mitigated with lesser resources. So a major socioeconomic gain can be achieved by the implementation of the SunCare Hub.
- **Lifetime.** As mentioned above, the lifetime of a monocrystalline solar panel is around 25-30 years. However, the solar panel lifetime is also dependent on the degradation rate, or the yearly energy production loss as the efficiency of the solar cell decreases. This degradation rate is around 0.3%-1%.

4 Discussion

Connecting to the introduction, the SunCare Hub is attempting to be a part of fulfilling the UN's SDGs, addressing both rural depopulation and providing sustainable health care. The mobile clinic supports SDG 3 (Good-health & Well-being) by improving access to healthcare in remote areas, SDG 7 (Affordable & Clean Energy) by utilizing solar power, SDG 10 (Reduced & Inequalities) by reaching marginalized communities, and SDG 11 (Sustainable Cities & Communities) by operating as a mobile unit based on solar power. The technical feasibility and holistic impact of this solar-powered healthcare solution in Sweden and Spain, considering environmental, societal, and economic implications will be discussed in this section.

The study have employed Equation (1) to estimate the required solar panel area for the SunCare Hub, taking into account assumed energy consumption, solar irradiance, and efficiency. Two distinct locations, Sweden and Spain, were considered, revealing significant variations in the required solar panel area due to differences in solar irradiance and sunlight hours. Notably, Sweden exhibited a wide range of values, emphasizing the impact of its varying sunlight conditions. During Sweden's winter, characterized by limited sunlight, alternative power sources or storage solutions become essential. Whereas during the summer months both locations have similar solar conditions making the ability of providing Clean Energy (SDG 7) for the SunCare Hub feasible. Further it was found by rearranging the equation into Equation (2) that the available area, if filling the entire truck body, could sustain much higher loads and by introducing e.g., batteries allowing for short-term storage. This providing resilience for both daily and potentially weekly variations in solar irradiance, hence providing potential for continuous operation during unfavorable weather conditions.

In Spain, the SunCare Hub can address challenges associated with rural depopulation, offering sustainable healthcare services powered by solar energy. The potential to curb depopulation and preserve cultural heritage was emphasized. Similarly, in Sweden, the SunCare Hub could address challenges related to an aging population and limited healthcare access in remote areas. These two aspects are to be seen in the light of SDG 10 and 11, where the increased accessibility of healthcare in rural areas will eradicate inequalities between rural and urban populations. Further by ensuring that it is possible for people to stay in rural communities the preservation of cultural heritages is ensured. This should be seen as a way of facilitating more sustainable communities (SDG 11). The provision of regular health check-ups using clean energy could contribute to reducing healthcare service inequality and supporting elderly individuals facing difficulties with digital healthcare solutions which is strongly related to SDG 3.

The environmental impact of the SunCare Hub was analyzed, focusing on the production and disposal of solar panels and batteries. While acknowledging the energy-intensive manufacturing processes, the study emphasized the overall environmental benefit over the lifetimes of these components. Wrapping up, we came to the conclusion that, although the manufacturing and recycling processes are not as environmentally friendly as one would like, the practice of using PV panels compensates for carbon emissions in 1-2 years.

The economic impact of the SunCare Hub was investigated, highlighting potential benefits for both Spain and Sweden. The repopulation of rural areas was seen as a catalyst for increased economic activity, employment creation, and improved local businesses. Additionally, the provision of accessible healthcare was identified as contributing to a more cost-effective healthcare system and socioeconomic benefits through early detection and treatment.

5 Conclusion

In conclusion, the SunCare Hub presents a promising solution for providing healthcare services in remote areas, addressing societal challenges related to depopulation, limited healthcare access, and environmental sustainability. While challenges exist, such as extreme weather conditions and the need for responsible waste management, the overall impact on society, the environment, and the economy suggests that the SunCare Hub could be a valuable addition to rural healthcare strategies in both Spain and Sweden. Further research and practical implementation are crucial to refining and validating the proposed approach.

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Appendix

In this Appendix the two figures for calculating daily seasonal averages for both Spain and Sweden are presented to ease the reader in further understanding of how this work was performed.

In Figure A.1 the monthly GHI's for Spain is presented and in Figure A.2 the yearly variation of the global solar irradiance was used for the calculations.

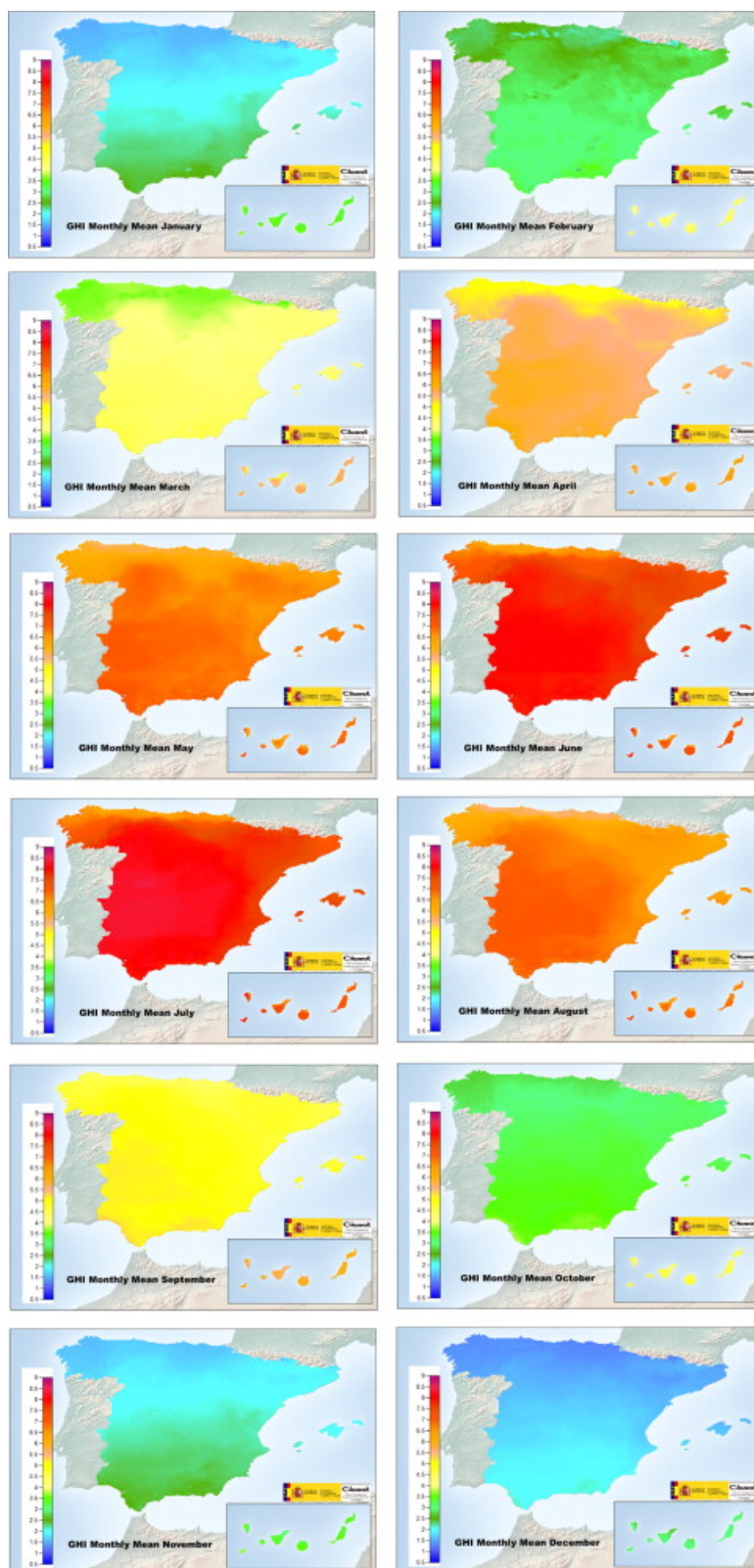


Figure A.1: Reference material used to calculate daily seasonal averages of global solar irradiance in Spain [21].

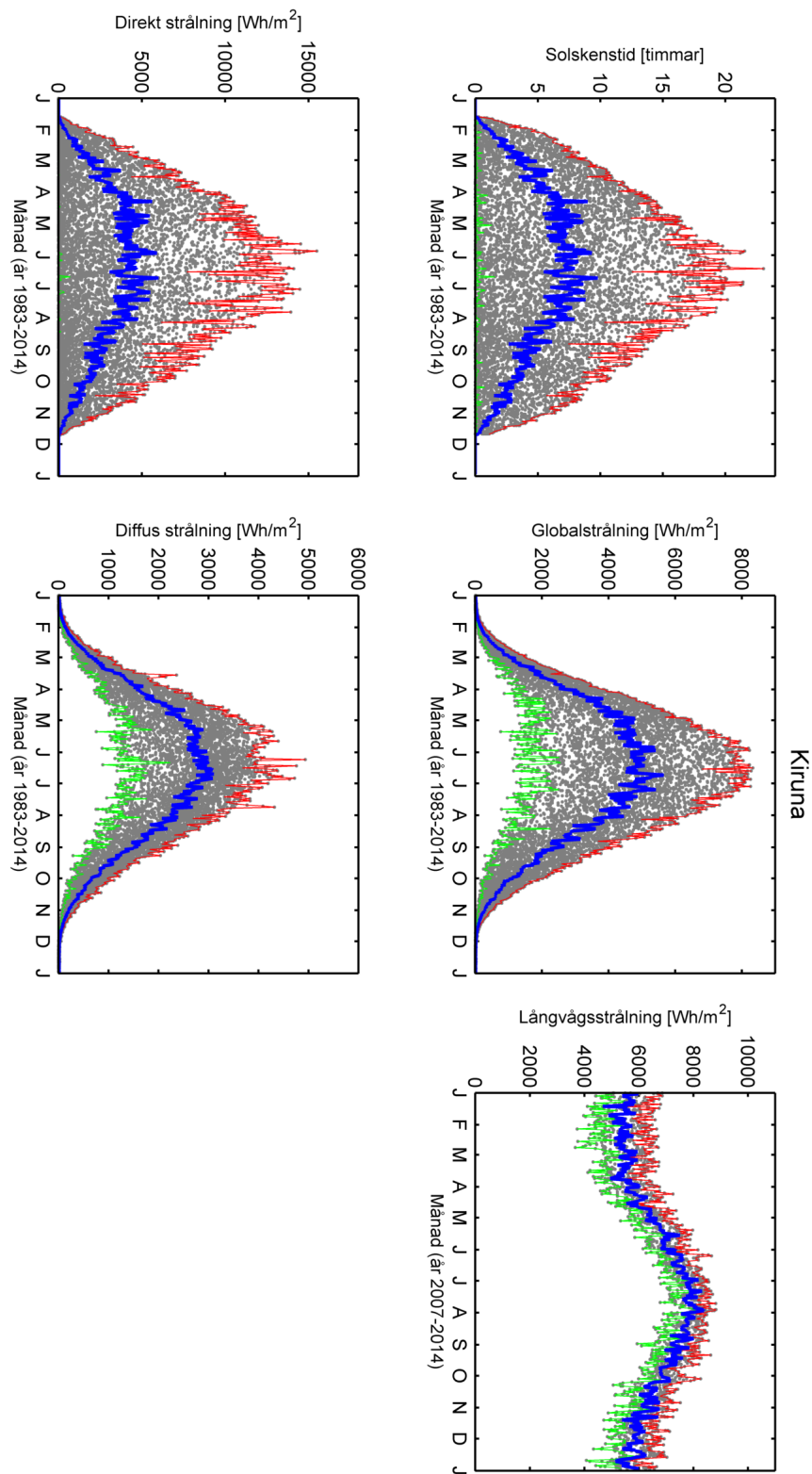


Figure A.2: Reference material used to calculate daily seasonal averages of global solar irradiance in Sweden [22].