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# Perspectives and practices of Photovoltaic (PV) energy producers in Greece: A qualitative study of renewable energy communities

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## Abstract

Energy communities are cooperatives that promote a solidarity-based economy, innovation, and sustainable energy production, storage, and management. This study investigates the factors that facilitate or hinder the development of the photovoltaic (PV) energy sector, as perceived by members of PV energy communities, alongside their practices regarding the maintenance and cleaning of PV parks. It further explores whether there is a genuine need for a product that could improve the efficiency and performance of photovoltaic panels. To address these aims, 177 interviews were conducted with PV energy producers and members of various energy communities across Greece. The findings offer valuable insights into both the current state and future prospects of the PV energy sector, highlighting key challenges such as bureaucracy, licensing complexities, frequent regulatory changes, limited network availability, and insufficient funding. Nonetheless, participants remain optimistic about increased production and foresee future projects of larger scale focusing on storage solutions. Notably, around 10% of respondents do not implement any cleaning practices for their PV panels, yet express interest in innovative products that could enhance efficiency. Collaborative efforts are deemed essential.

***Keywords:*** Energy Communities; Solar Energy; Photovoltaic Energy Producers



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## 1. Introduction

Renewable Energy Sources (RES) are considered crucial for achieving international short- and long-term goals regarding climate protection and the transition from the era of energy production from fossil fuels to the era of energy production from RES to drastically reduce greenhouse gas emissions. This transition is considered more than important, aiming at protecting the environment and human health. Therefore, with the growing concern about global warming and the increasing issues from the environmental impacts associated with fossil fuels, the transition to the use of RES is imperative through the significant reduction of greenhouse gas emissions and the adoption of high-efficiency energy policies.

The International Renewable Energy Agency report supports that up to 90% of the goals set to protect the planet under the Paris Agreement can be achieved through the rapid development of RES use with a simultaneous increase in energy efficiency (International Renewable Energy Agency, 2017). To achieve these goals, the European Union (EU) has already set targets for 2030 as part of its energy strategy (Ahmad et al., 2020) to be the first climate-neutral continent by 2050.

Among the EU initiatives is the legal development of energy communities in 2019. Energy communities are cooperatives through which citizens (prosumers), local authorities (e.g., municipalities), and SMEs can be active in the energy sector, utilizing clean forms of energy. Energy communities aim to promote a solidarity economy, innovation in the energy sector, fight energy poverty, promote sustainable energy production, storage and management, self-production and self-consumption, and improve energy security and autonomy. The European Commission's Clean Energy for All Europeans Package reaffirms the importance of prosumers and their collective forms in the future energy system. The EU legal framework explicitly recognizes and specifies various forms of community energy as 'renewable energy communities' and 'citizen energy communities'. According to the European Commission, by 2030, energy communities driven by citizens are projected to own around 17% of wind and 21% of solar power.

Solar energy is considered the primary RES, with a share of 59% of the total energy from RES in 2019 (International Energy Agency, 2020) and a share of 12.8% of the total of all energy types in 2022, with a forecast to surpass 20% by the end of 2026 (International Energy Agency, 2023b), numerous investments has already been made almost in every part of the planet. Broadly speaking, active solar energy technology may be classified into photovoltaic and solar thermal technology (Herrando and Markides, 2016). The prospects of the sector are more than promising. They can be attributed to factors such as economies of scale, constant improvements in Photovoltaic (PV) panels' performance, and national and international incentives. Moreover, the cost of PV panels has decreased by up to 90% compared to 2009 (Greek Association of PV Companies, 2023). Consequently, there was a 35% increase in the annual growth rate of PV investments worldwide from 2010 to 2019 (Philipps and Warmuth, 2023). Additionally, the performance of new PV system installations exceeded 100GW worldwide for the 3rd year in a row (International Energy Agency, 2020) and is expected to reach ~293GW globally by the end of 2023 (International Renewable Energy Agency, 2023). Solar PV generation increased by 270 TWh (up 26%) in 2022, reaching almost 1300 TWh with an estimated 1991 TWh by the end of 2024 (International Energy Agency, 2023b).

Furthermore, investments in solar are set to overtake oil for the first time in 2023 (International Renewable Energy Agency, 2023). Regarding the EU, the importance of solar energy on its strategic policy is depicted by the 38GW PV systems investments in 2022, a 50% increase compared to 2021 (International Energy Agency, 2023b). Another report from the International Energy Agency (2023a) predicts that energy from PV systems' additions will reach 81.9GW in the EU in 2023-2024.

Since renewable energy communities and the solar energy sector play a significant role in the energy transition, providing social, economic, and environmental benefits, it is imperative to understand these communities and their practices better. Therefore, the goals of the present study are threefold: a) to investigate the perceptions of energy communities' members and, specifically, PV energy producers, b) to examine the maintenance and cleaning practices of PV energy producers and their satisfaction with the PV systems' performance and c) to understand their need and openness for a new PV performance enhancing product. At this point it should be noted that this study is a market research effort and part of a broader funded project. The study contributes to the literature by understanding the PV energy community members' views about the sector. Moreover, because investments in PV systems are high and their cost is significant, the study benefits PV energy members, producers, service providers, and policymakers with insights into the maintenance and cleaning practices.

The rest of the paper is organized as follows. First, we present the review of the literature along with the method of the study. Next, we present the study's results and conclusions with the limitations and future research recommendations.

## 2. Literature review

### 2.1. The renewable energy communities

Energy communities may be seen as facilitating communal energy initiatives via inclusive and participatory governance, aiming to provide advantages for its members or the surrounding community (Roberts et al., 2019). Two distinct formal definitions exist of energy communities: 'citizen energy communities' and 'renewable energy communities' (European Parliament and Council of the European Union, 2018)

Cooperatives are the predominant form of citizen-led initiatives. Cooperatives are social and economic enterprises facilitating the community ownership and management of renewable energy projects (Yildiz et al., 2015). According to Walker (2008), individuals residing in the local vicinity or nearby regions have the opportunity to engage in the funding of renewable energy projects by purchasing shares. In some instances, individuals can both use and distribute renewable energy resources.

Renewable energy communities are emerging as novel non-commercial organizations that, although participating in economic endeavors, are primarily focused on delivering environmental, economic, or social advantages to the community rather than pursuing profit maximization (REScoop.EU, 2020). The advocacy for energy communities has many advantages, as it fosters the use of sustainable energy sources, hence facilitating the mitigation of greenhouse gas emissions. Additionally, they facilitate a transformation in consumer-producer dynamics within the energy sector, promoting a move towards prosumption. Research suggests that this change can enhance sustainable practices and foster a culture of sustainability. Finally, they have the potential to initiate further transformations towards the adoption of sustainable lifestyles outside the realm of energy use. The benefits mentioned above provide a persuasive rationale for the European Union to endorse the promotion of energy communities, advancing its goals for energy transition and contributing to a significant reduction in carbon emissions (Sokołowski, 2020).

Renewable energy communities are sustainable communities seeking to *protect and enhance the environment* (e.g., use energy, water, and other natural resources efficiently), *meet social needs* (e.g., protect human health and amenities through safe, clean, pleasant environments), and p*romote economic success* (e.g., create a vibrant local economy that gives access to satisfying and rewarding work without damaging the local, national, or global environment) (Agyeman, 2005). According to Tsiotsou et al. (2023), energy communities represent a notable manifestation of advanced sustainable communities in energy services. These communities facilitate the harmonious collaboration and effective use of resources among many stakeholders, including national entities, local authorities, and individual citizens, to facilitate the transition towards cleaner energy sources. Thus, renewable energy communities play a significant social, environmental, and economic role in our society.

## 2.2. The solar energy sector

Innovative solar power technology development is crucial to addressing the growing global energy demand. Solar technology will effectively minimize and relieve challenges related to energy security, energy democracy, climate change, unemployment, and other pertinent concerns. Moreover, solar energy is regarded as an environmentally friendly, dependable, and sustainable kind of energy.

The field of solar technologies is experiencing significant expansion; however, it is encountering several technical challenges. These challenges include low efficiencies of solar cells, suboptimal performance of balance-of-systems (BOS), economic barriers such as high initial costs and limited financing options, and institutional obstacles like inadequate infrastructure and a shortage of skilled personnel.

Over time, the efficiency of solar cells has increased through continuous improvement of applied materials and manufacturing methods. In the early years of PV, the efficiency of solar cells did not exceed 5.7% (Forrest, 2005). However, although efficiency has almost tripled, it remains at a reasonably low level (~18%). The best performance is obtained in monocrystalline silicon structures (Fisac et al., 2014). Other construction materials of solar cells that have already been utilized are cadmium telluride (8%-9% performance efficiency), copper diselenide (10%-13%), polycrystalline silicon (12%), foamed polycrystalline silicon, amorphous silicon, and ceramic molecular materials (Gratzel, 1991). Apart from the type of material applied, several other factors impact the efficiency of PV panels and are analyzed as follows:

### *2.2.1. Operating temperature*

Investigating the effect of temperature on PV systems, Fesharaki et al. (2011) concluded that there is a direct relationship between installation efficiency, solar radiation, and PV system temperature. More specifically, they proved a negative relationship between PV efficiency and operating temperature to the extent that it depends on other factors, such as installation type and weather conditions. Rajvikram and Leoponraj (2018) also pointed out that high operating temperature reduces the efficiency and lifetime of the PV panels. In recent studies, creating grooves in monocrystalline silicon PV panels improved heat dissipation and increased efficiency (El-Atab et al., 2019).

As aforementioned, the operating temperature of the PV cells plays a vital role in the lifetime of the PV system components in addition to its efficiency (Rajvikram and Leoponraj, 2018). When operating at high temperatures, the operating elements degrade and lose their efficiency sooner. Therefore, operating PV panels to lower temperature increases their lifetime (Sharma et al., 2018). Additionally, another critical factor regarding the PV panel's lifetime is the main material of its construction and production process. According to El-Atab et al. (2019), creating grooves in monocrystalline silicon PV panels creates flexibility, increasing the resistance of the installations against natural and technical phenomena.

### *2.2.2. Radiation concentration*

According to Yilmaz et al. (2015), the solar radiation absorbed by the PV panels can be increased up to 41% when there is a two-axis mechanism in the installation to track the sun's position. Although the increase in solar radiation uptake is relatively high in this case, the increase in the electricity generated ranges between 10% and 45% compared to fixed position installations (Nsengiyumva et al., 2018; Singh et al., 2018). In some cases, however, the sun positioning mechanism consumes more than 5% of the generated energy, and the maintenance of this type of PV installation is more expensive (Nsengiyumva et al., 2018).

### *2.2.3. Reflection degree*

The efficiency of PV panels is mainly affected by optical and thermal losses, mainly attributed to reflections that also lead to an increase in PV system temperature. Sunlight is reflected and refracted because of the reflective effect of the PV panel surface, even though it is clean. As a result, only some of the solar rays reach the PV cells. Because of this sunlight reduction, a decrease in electrical power is also caused. This phenomenon has been observed in materials broadly used in anti-reflection coatings, such as SiO2, MgF2, TiO2, Si3N4, and ZrO2. However, by applying multi-layer coatings of these materials, the reflectivity is reduced, and the light uptake by the solar cells is increased (Sarkın et al., 2020). Moreover, the high reflectance and operating temperatures reduce the PV panels' efficiency and lifetime (Rajvikram and Leoponraj, 2018). Additionally, Cotfas and Cotfas (2019) mentioned that the maximum power produced by PV systems can be increased if more radiation is concentrated through physical/passive or technical/active reflection in PV panels.

### *2.2.4. Penetrability – clearness*

The PV system produces power depending on how much sunlight reaches its solar cells. This amount of sunlight, however, is reduced because of environmental factors such as dust accumulation, inorganic deposits, organic residues, salts, and oxides. These elements decrease not only its efficiency but also its lifetime. Hence, PV panels are coated with anti-reflective and self-cleaning coatings to overcome these issues. Among self-cleaning applications, the best-applied solutions are superhydrophobic surfaces based on materials such as Al2O3, TiO2, and Si3N4. Double and triple-layer coatings also have successful results in terms of surface adhesion and durability (Sarkin et al., 2020). According to Guo et al. (2015), the relationship between the level of environmental dust concentration in the PV panels and their performance is inversely proportional.

### *2.2.5. Weather conditions – seasonality*

Once exposed to outdoor conditions, PV panels are greatly affected by weather conditions. Many studies confirmed the impact of air temperature on their efficiency (e.g., Chaichan and Kazem, 2016). Their results show a decrease in their efficiency when there is an increase in the PV system's and air temperatures.

According to Chaichan & Kazem (2016), solar air temperature is a heating source from 8 a.m. until 5 p.m. in the winter and 7 p.m. in the summer and as a cooling source all the other hours of the day. However, the high relative humidity in the study area caused a decrease in solar radiation intensity, impacting lower solar air temperature (Chaichan and Kazem, 2016). In another study, Guo et al. (2015) proved that the efficiency of PV panels is positively correlated with wind speed and negatively correlated with the humidity of the area where the PV systems have been installed.

#### *2.2.6. Complementary efficiency enhancement products and services*

As aforementioned, if you can maintain the temperature of the PV cells within a specific temperature range, an optimum PV system performance can be achieved. In various studies (e.g., Abdolzadeh and Ameri, 2009; Dorobantu and Popescu, 2013; Baskar, 2014; Sharma et al., 2018), researchers reduced power loss attributed to PV system's overheating, especially during midday operating hours, by installing water cooling systems in the PV panels. Teo et al. (2012) designed and developed a PV cell cooling system through parallel rows of conductors connected via multiple inlets and outlets. As a result, the continuous airflow significantly reduced the temperature of PV cells, increasing their efficiency from 12% to 14%.

According to Abd-Elhady et al. (2016), an efficiency increase can be achieved if a thin layer of oils (1 mm thick) is applied to the surface of the PV panels. Remarkably, they proved a 20% increase in efficiency by using vacuum pump oil, provided that the correct operating temperature was maintained on the PV mirror. On the other hand, a negative side effect was the increase in temperature in the PV panel because of the high degree of oil permeability. Thus, they recommend this method to be applied in colder climate PV installations (Abd-Elhady et al., 2016).

Using anti-reflective coatings, an increase in solar cell efficiency can be achieved by increasing the output power and, thus, causing a reduction in optical losses. Anti-reflective chemicals, such as aluminum oxide and tantalum pentoxide ($Al_2O_3$- $Ta_2O_5$-$Al_2O_3$), are coated as a double layer. The chemicals are deposited on the solar cell's surface by forming a thin coating. With this method, the loss attributed to reflection is reduced while the efficiency of PV panels is increased (Rajvikram and Leoponraj, 2018).

## 3. Methodology

### 3.1. The context of the study

The study took place in Greece, where the energy sector is one of the main pillars of the domestic economy, with significant and continuous investments over the years. However, the ever-increasing global demand for energy and the simultaneous increase in environmental pollutants have significantly forced the country to RES, mainly solar energy. Based on a series of strategic political actions to achieve European and international goals, Greece, as a member of the EU, has already invested and continues to invest significantly in solar energy through the technology of PV systems. The country's focus on this RES, as part of its environmental and energy policy, is also attributed to several other factors, such as its geographical location, its climate, and the diversity of its terrain; all of them are considered extremely important. As a result, according to the International Energy Agency (2020), the energy from solar panels in Greece corresponded to 8.1% of its total energy production in

2019 (EU: 4.9% - Worldwide: 3%); a percentage that placed Greece in the fifth place in the world ranking together with Australia and behind only from Honduras (14.8%), Israel (8.7%), Germany (8.6%) and Chile (8.5%).

A more recent report mentions that the energy from PV systems in the country corresponded to 13.6% of its total energy production in 2022 (Greek Association of PV Companies, 2023). Furthermore, the interconnected PV systems installed reached a total capacity of 1392.5MW in 2022. The PV investments reached 85% of all newly installed RES capacity in 2022 in the country, with a total cost of 1.08 billion euro (Greek Association of PV companies, 2023).

As regards the prospects of solar energy investments in Greece, these are considered very promising. Specifically, the National Plan for Energy and Climate (Ministry of Environment and Energy, 2019), which was finalized in November 2019 and is essentially based on the broader environmental and energy strategy of the EU and the Paris Agreement, clearly defines the country's strategic policy, in line with the global trend, for significant investments and further development of PV systems (Ministry of Environment and Energy, 2019). A recent study indicates that the solar energy industry is progressing, accompanied by the emergence of additional support services (e.g., cleaning and storage services) to enhance the effectiveness and functioning of renewable energy sources (Tsiotsou et al., 2025). The country intends to reach 7.7 GW by the end of 2030 to 12.1 GW in the same year. Hence, the participation of PV systems in the country's total energy production is intended to rise from 8.1% in 2019 to 20.7% in 2030.

To achieve these goals, Greece developed the largest PV park in Greece and one of the five largest in Europe, close to Kozani. It has a capacity of 2.3GW and can produce 350GWh of zero-emission energy annually. The area where it was built was strategically chosen because of the country's strategy to eliminate lignite. The broader area of Kozani was the leading electricity supplier through lignite for decades. In particular, the project consists of three sections and has a capacity of 2.3 GW.

Meanwhile, new PV projects are being launched. For instance, there are several related projects, such as the PV project of the company "Solar Florina" in Florina with a capacity of 749 MW, the project of "Solar Krovili" in Rodopi with a capacity of 565 MW, and the projects of the companies "Idea Light" and "IliakoPower" in Kilkis with a capacity of 460 MW and 432 MW respectively. Based on these facts, it is more than evident that solar energy is the fundamental pillar supporting the country's energy and environmental policy with a promising present and future.

### 3.2. Questionnaire creation

In-depth interviews were used to collect the data for the study. A qualitative exploratory approach was chosen, using a semi- structured questionnaire with close and open-ended questions. Interviews were conducted by phone and online, depending on the availability of respondents.

The questions were developed based on empirical studies from previous researchers (Garlet et al., 2019; Kayser, 2016; Stević et al., 2019; Taleb and Pitts, 2009; Wong and Ellul, n.d.). As a result, 5 Sections were regarding PV energy producers with the following categories:

- Introductory questions (SECTION A)
- Attitudes and opinions about the PV industry (SECTION B)
- General information on PV (SECTION C)

- PV maintenance and cleaning (SECTION D)
- Future intentions (SECTION E)

The third stage included a pilot testing of the questionnaire with a PV energy producer. The questionnaire was revised and finalized.

### 3.3. Sampling – compiling a list of sample businesses

A convenience sample was used to collect the data from a list of businesses. Specifically, a list of various PV energy producers-members of energy communities was compiled from the Panhellenic Federation of Associations of Photovoltaic Electricity Producers, the Association of Photovoltaic Companies, and the catalog of the Ministry of Environment, Energy and Climate Change. Specifically, the list included 250 electricity producers from PV Stations – members of energy communities. An invitation letter asking for their participation in the study was sent via email by the Panhellenic Federation of Producers' Associations (POSPIEF). One hundred and seventy seven (177) replied positively and were interviewed by the scientific team members.

## 4. Results

### 4.1. Perceptions of the PV communities' members

This section included questions that aim to capture PV energy producers' views on the opportunities in solar energy communities, threats regarding the development of the PV systems market, and the future of the communities and the RES sector. The results were extracted based on the text analysis tool Voyant, a web-based text mining and visualization platform. This software facilitated an initial exploration of the corpus by generating visualizations such as word clouds, frequency lists, and keyword-in-context (KWIC) displays, allowing for the identification of prevalent terms, emerging themes, and patterns within the data. The insights gained from Voyant's analyses complemented the manual coding process, enhancing the rigor and transparency of the study by providing an additional layer of evidence for thematic interpretation. All visualizations and statistical outputs from Voyant were examined critically to contextualize quantitative patterns within the qualitative research framework.

At this point it should be noted that the open-ended responses on the questionnaire were coded using specific words that reflected the main concepts and ideas expressed by the participants. Each answer was carefully examined, and key terms were assigned to represent the core meaning of the responses. This process allowed for the organization of qualitative data into meaningful categories while maintaining the essence of the participants' views

The first question concerned their opinion on how Greece's PV market has evolved over the last five years. More specifically, PV energy producers focused on the following: market growth (frequency: 29), rise (frequency: 25), stagnation (frequency: 27), positive (frequency: 12), problems (frequency: 10), and decrease (frequency: 3).

The second question was about their opinion on where they see specific opportunities for the PV sector in Greece in the next five years. Most respondents mentioned storage (frequency: 43), large projects (frequency:

39), large parks (frequency: 12), maintenance (frequency: 10), installation (frequency: 10), and net metering (frequency: 7).

The third question concerns the respondents' predictions about the PV production/sector for the next five years. Most believe that production will increase (frequency: 100) and the sector will have an upward trajectory for Greece (frequency: 30). They speak of a sharp increase in photovoltaic energy without overlooking that its development will depend on many factors.

The last question in this category concerned the most significant obstacles in installing and exploiting PV and other renewable energy sources in Greece. The vast majority mentioned bureaucracy (frequency: 54), problems they face with the electricity distribution company, DEDDIE (frequency: 30), funding, and the lack of available networks (frequency: 58). More specifically, the bureaucracy concerns problems with the government, frequent changes in laws, lack of staffing of the competent bodies, delays regarding the requested permits. At the same time, other problems concern the saturated networks, the obsolete PPC network, the marginalization of small producers, the violation of signed contracts, banks not granting them financing, and the lack of information.

## 4.2. Sample description

This section included questions whose general objective was to record data about the years of operation of the companies, the total installed capacity of each company's solar power plants, the average performance, and the type of Solar Panels that have been used. Initially, PV energy producers were asked to answer in which prefectures they have their PV stations. Based on the answers of the producers, they have 127 PV stations/parks, which are located in 35 prefectures of the country, with the most in the prefectures of Thessaloniki, Kilkis, Halkidiki, Drama, Pella, Pieria, Grevena and Larissa (Figure 1).

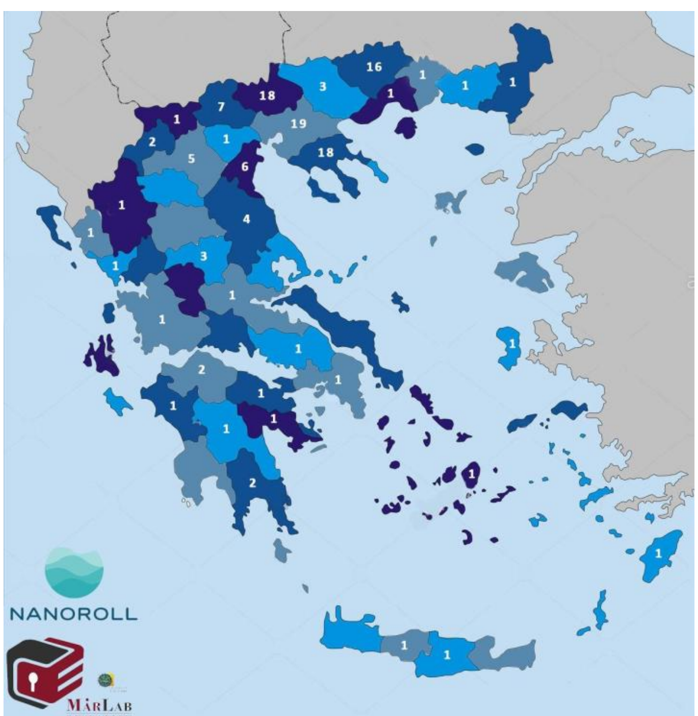


**Figure 1.** Location of PV energy producers

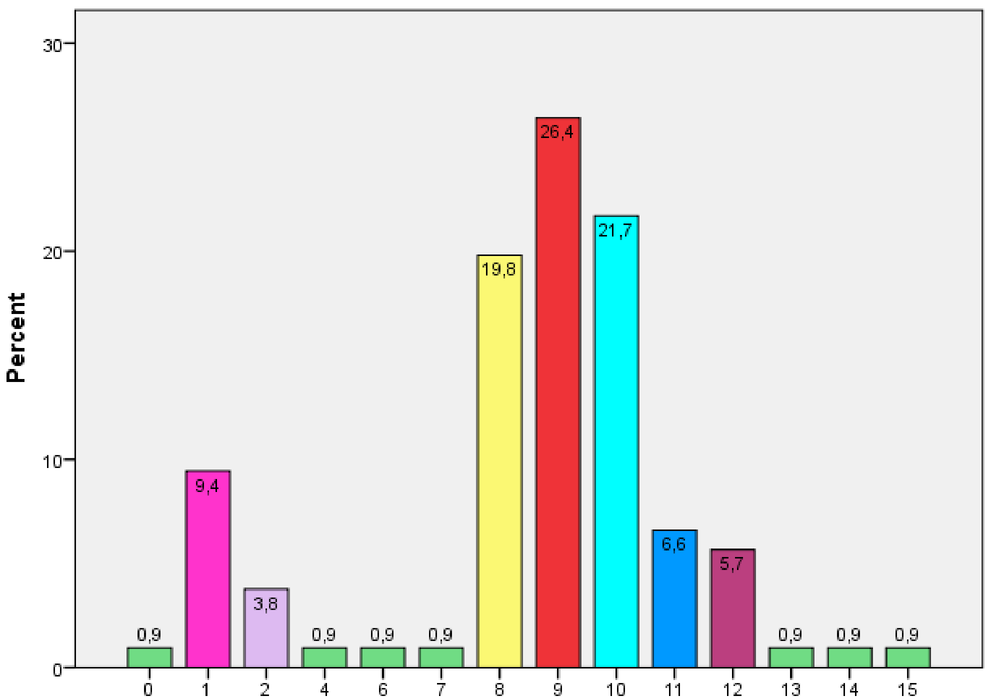


**Figure 2.** Years of operation of PV Stations

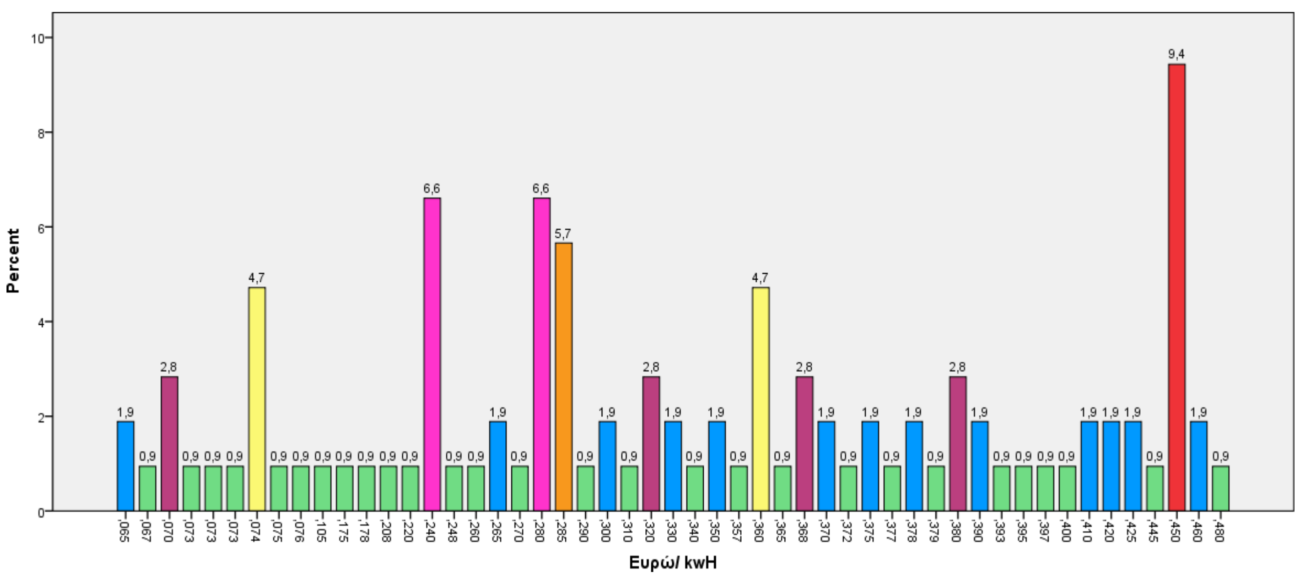


**Figure 3.** Average Electricity Selling Price per kWh among PV Energy Producers

Then, PV energy producers were asked to provide information about how long their business has been operating. The average operation of PV stations is 8.26 years (Figure 2). In addition, 63.1% cumulatively stated that the station's PV has been operating for over eight years. Specifically, 21.7% stated that the Station's PV has been operating for ten years, 26.4% that it has been operating for nine years, and 19.8% for eight years. At the same time, 9.4% stated that the PV of the Station has been operating for a year and 3.8% for two years. On the other hand, 19.8% answered that their PV plant has been operating for eight years, 9.4% for one year, and 3.8% for two years.

The following question concerned the average price the PV energy community members - PV energy producers sell their electricity in euro/kWh (Figure 3). The selling price ranged from 0.48 euro/kWh to 0.065 euro/kWh. Most producers (52%) stated that they have locked in a selling price of up to 0.33 euro/ kWh. However, there is a large dispersion of prices. The average selling price of electricity per kWh is 0.30 euro/kWh, while the prevailing prices are 0.24 euro/kWh (6.6%) and 0.275 euro/kWh (6.6%). It is worth noting that 15.1% have closed "low" prices below 0.076 euro/kWh, which means they were developed in the last two years. In this category, 0.074 euro/kWh is the prevailing average price (4.7%), followed by 0.07 euro/kWh (2.8%). The percentage of producers who have locked in a compensation price above 0.45 euro/kWh is also important since it amounts to 13.2%. The prevailing price is 0.45 euro/kWh (9.4%).

Next, PV energy producers provided information about the total installed capacity of all their PV Stations. According to the responses of PV electricity producers, the average installed power of PV in kW amounts to 439.31 kW. Most producers (56.6%) have PV stations with a total power of up to 100 kW (Figure 4). More specifically, 39.6% stated that the total installed power of the Stations' PV is 100kW, while 10.4% stated that the total installed power of the Stations' PV is 20 kW. At the same time, 8.5% stated that the total installed power amounts to 500 kW and 7.5% to 1 mW. Only 5.7% of the producers stated that the total installed power of the PV stations exceeds one mW.

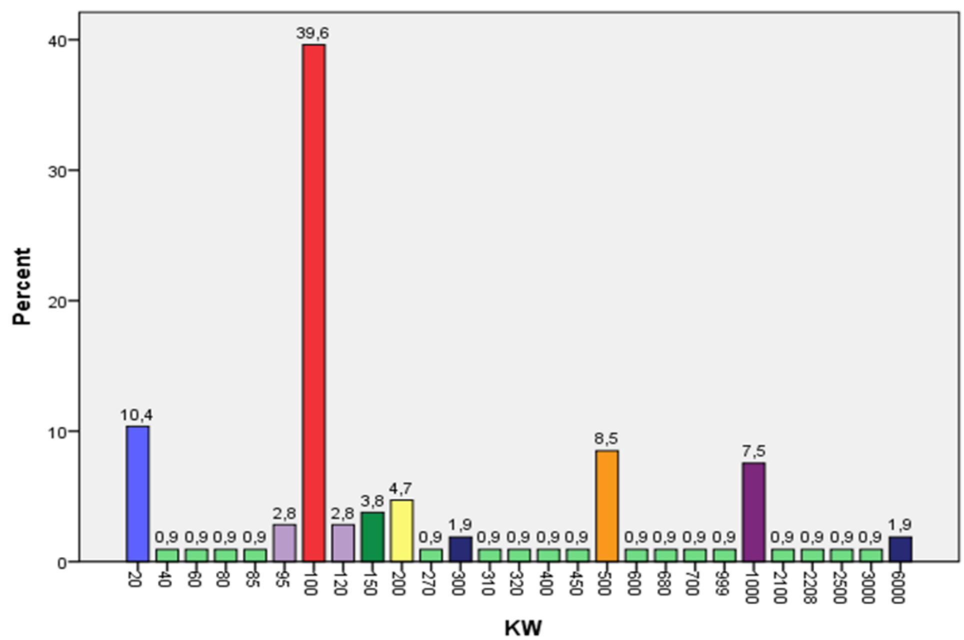


**Figure 4.** Total installed Power of PV Plants (kW)

The next question concerned the average efficiency of the PV Stations per installed kW. Specifically, PV electricity producers had to answer about the average efficiency in kWh per installed kW of their PV plants. According to the answers (Figure 5), the average performance of the PV plants is 1573.97 kWh installed kW. More specifically, most producers (51%) cumulatively answered that the average efficiency per installed kW reaches 1520 kWh, and 15.6% answered that the average efficiency reaches 1500 kWh. In comparison, 9.4% answered that the average efficiency per installed kW ranges at 1450 kWh. On the other hand, a total of 32.3% answered that the average efficiency exceeds 1580 kWh, and more specifically, a percentage of 5.2% answered that the average efficiency reaches 2000 kWh and a percentage of 2.1% 2.100 kWh. These yields concern PV Stations where tracker systems have been installed.

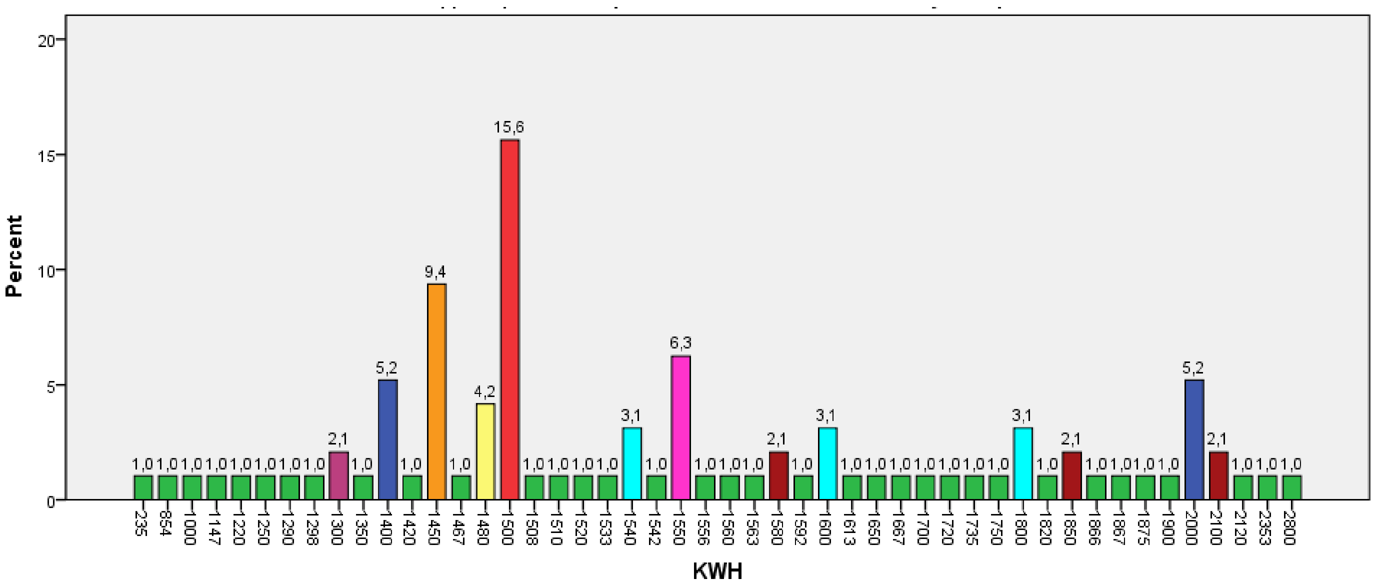


**Figure 5.** Average Efficiency in kW of PV Stations

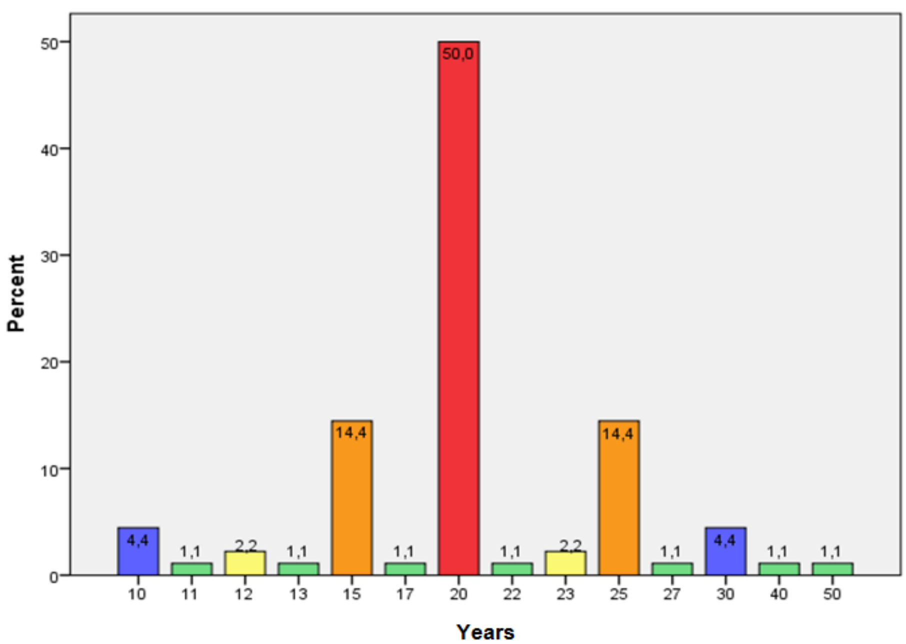


**Figure 6.** Average Life Time of PV Panels

Next, we asked PV power producers about the average lifetime of PV panels. The average of the responses regarding the lifetime of PV panels was 20.33 years (Figure 6). More specifically, 74.4% of the producers consider that the lifespan of PV Panels does not exceed 20 years. Of these, 50% of producers answered that the lifetime of PV panels is 20 years, 14.4% 15 years, and 4.4% ten years. However, 14.4% answered that the lifetime of PV panels reaches 25 years, and 4.4% that it reaches 30 years.

In the following question, we asked PV energy producers about the type of PV panels they use. Producers had to answer what kinds of PV panels they had installed. Polycrystalline panels generally dominate the producers' responses (Figure 7). Specifically, 65.3% answered they had installed polycrystalline panels and 27.6% monocrystalline. A percentage of 2% answered that they had installed Thin Film type panels, while a percentage of 5.1% answered that they had installed both polycrystalline and monocrystalline panels.

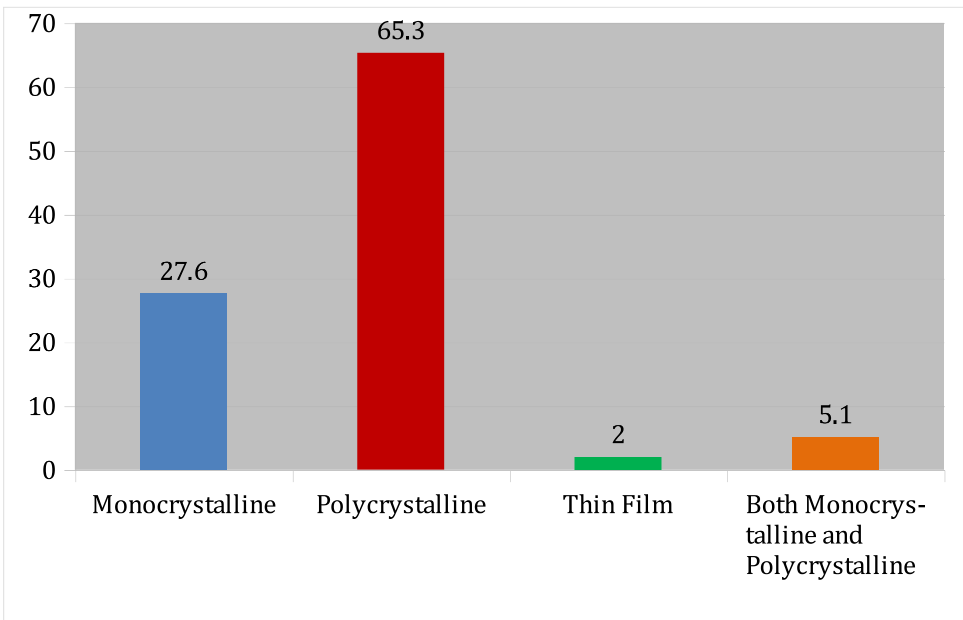


**Figure 7.** Type of PV Panels installed at the PV Stations

## 4.3. PV systems' maintenance and cleaning

This section included questions about the maintenance and cleaning of PV systems, particularly the maintenance methods, frequency of inspections, and cost.

The first question concerned the frequency of checks. The most significant percentage of producers responded that they performed checks twice a year (38.5%). Others perform maintenance inspections 3 - to 6 times per year (18.2%), daily (14.4%), once a year (13.5%), four times a year (9.6%), every month (5.8%), once every two years or every 15 days, three times a week or occasionally (1%) while 1.9% indicated that they did not know (Figure 8).

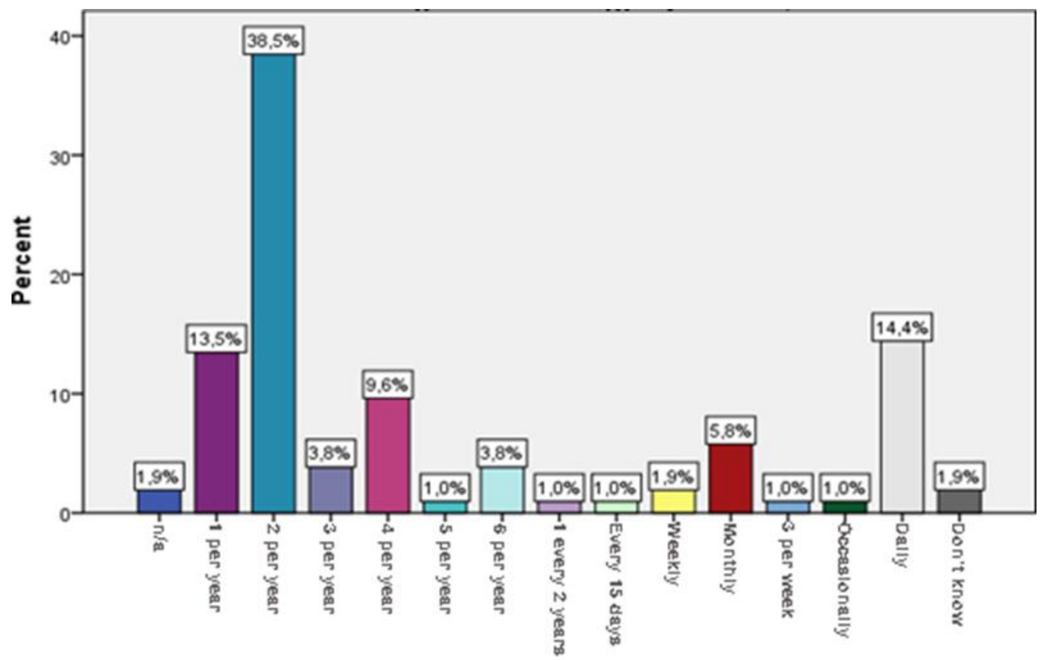


**Figure 8.** Frequency of PV inspections

Then, the next question was about who was responsible for the PV inspections. Most respondents indicated they hire a specialized company to perform maintenance checks (62.5%), while the rest do checks themselves (37.5%). As several self-checkers reported, they were industry-savvy (Figure 9).

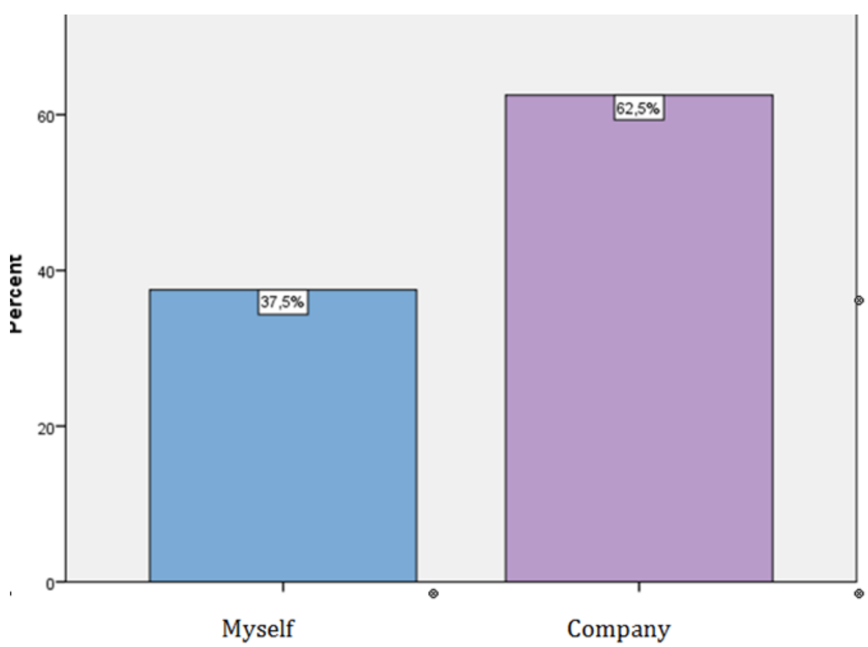


**Figure 9.** Agent responsible for PV inspections

The second question was about "Who cleans the solar panels?" The results showed that most producers turn to a cleaning company (61%), while 34.3% clean PV panels themselves. In the study sample, some producers did not clean their PV panels (4.8%) (Figure 10).

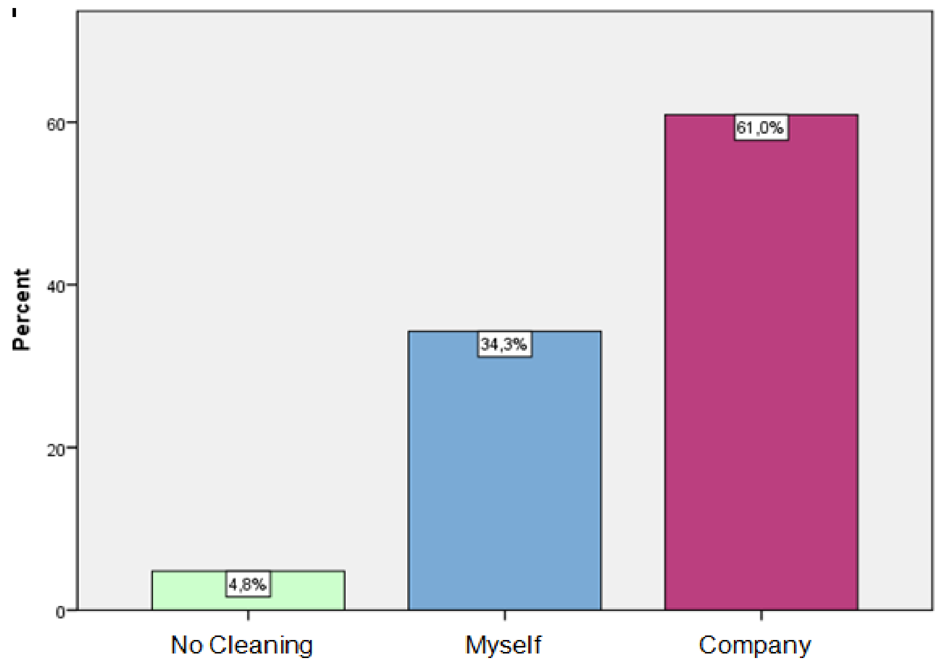


**Figure 10.** Agent responsible for PV cleaning

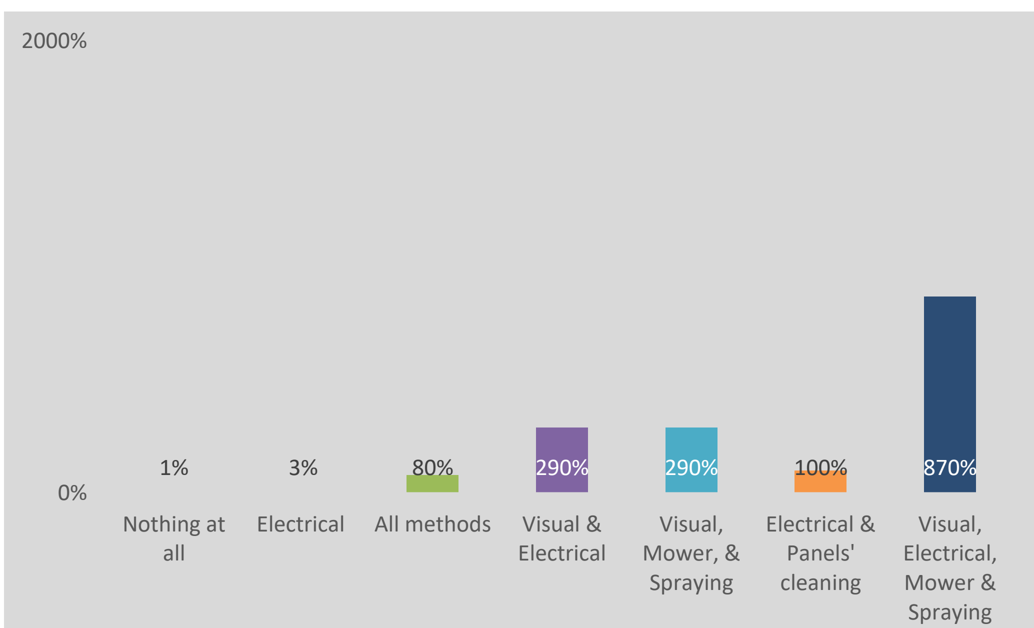


**Figure 11.** Preservation Method used by PV Energy Producers

The next question was about the PV maintenance methods the respondents use: 1) visual inspection (cable inspection, broken panel, rust, camera), 2) electrical inspection (operation, thermal camera, and efficient operation of the inverters), or 3) cleaning (washing – spraying or mowing)? The vast majority of producers carry out all necessary maintenance (80.8%), while only 8.7% use only optical-electrical-paper-cutting-sprinkling, electrical, optical-electrical or optical paper-cutting and spraying (2.9%), electrical-cleaning panels or nothing (1%) (Figure 11).

Regarding the money spent per year on the maintenance of the solar parks, the cost varies depending on the area of the PV park and the company. 21.8% of the sample paid between 1080€ to 1800€, 18.5% paid 3500€-17000€, 13.1% paid 600€-1000€, 10.8% paid 2000€ - 3000€, 9.8% paid 100€ - €500, 4.3% paid 2500€ while 9.7% indicated no cost (Figure 12).

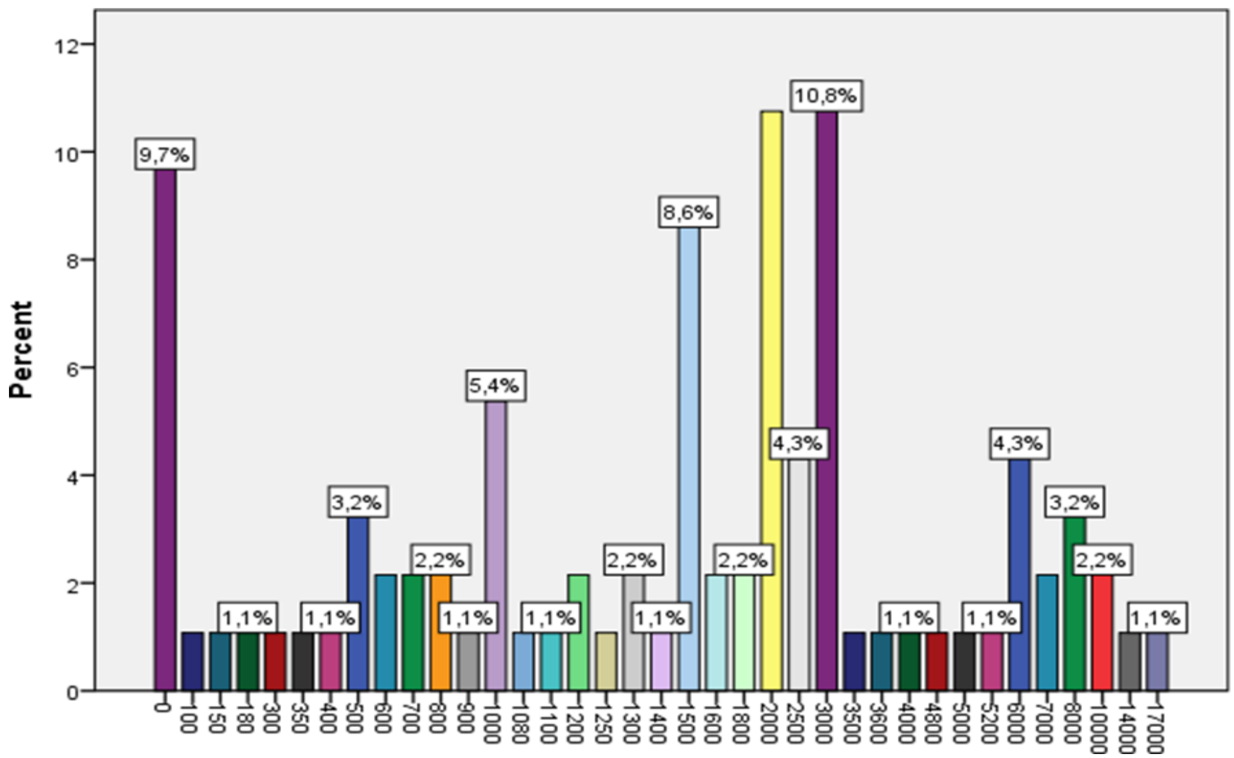


**Figure 12.** Amount of money spent on PV systems maintenance (in Euro)

In relation to the cleaning methods they use, the highest percentage, 26.5%, used brushes and deionized water, 19.6% used deionized water, and 18.6% did simple washing. However, 11.8% do not use anything for cleaning, so they do not clean. The respondents used telescopic brushes (6.9%), crawler or crawler with brushes and deionized water (4.9%), and other methods (8.8%), while 2.9% did not know about the cleaning method used (Figure 13).

The next question concerned the amount of money they spend per year on cleaning. 29.8% do not spend any money on cleaning the PV park, 9.6% spend between 250€ - €990€, 7.4% spend around 300€, 13.9% spend 20€ to 200€, while 16.2% spend more than 1000€ (Figure 14).

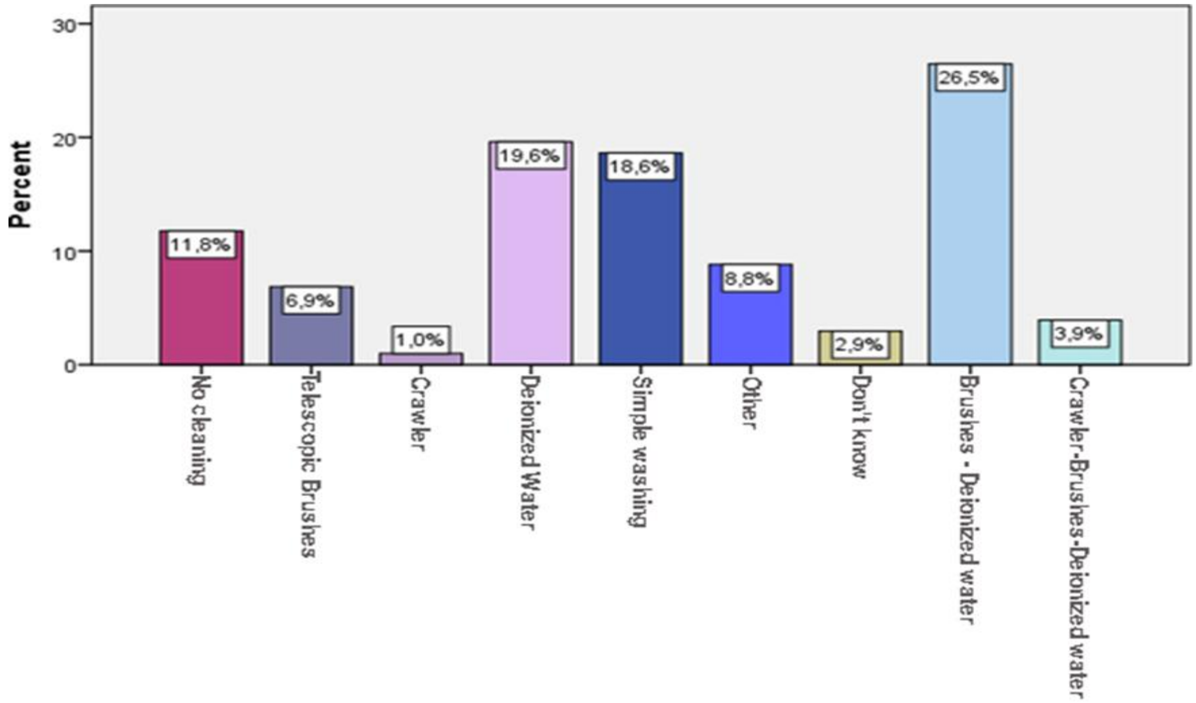


**Figure 13.** Cleaning methods used in PV systems

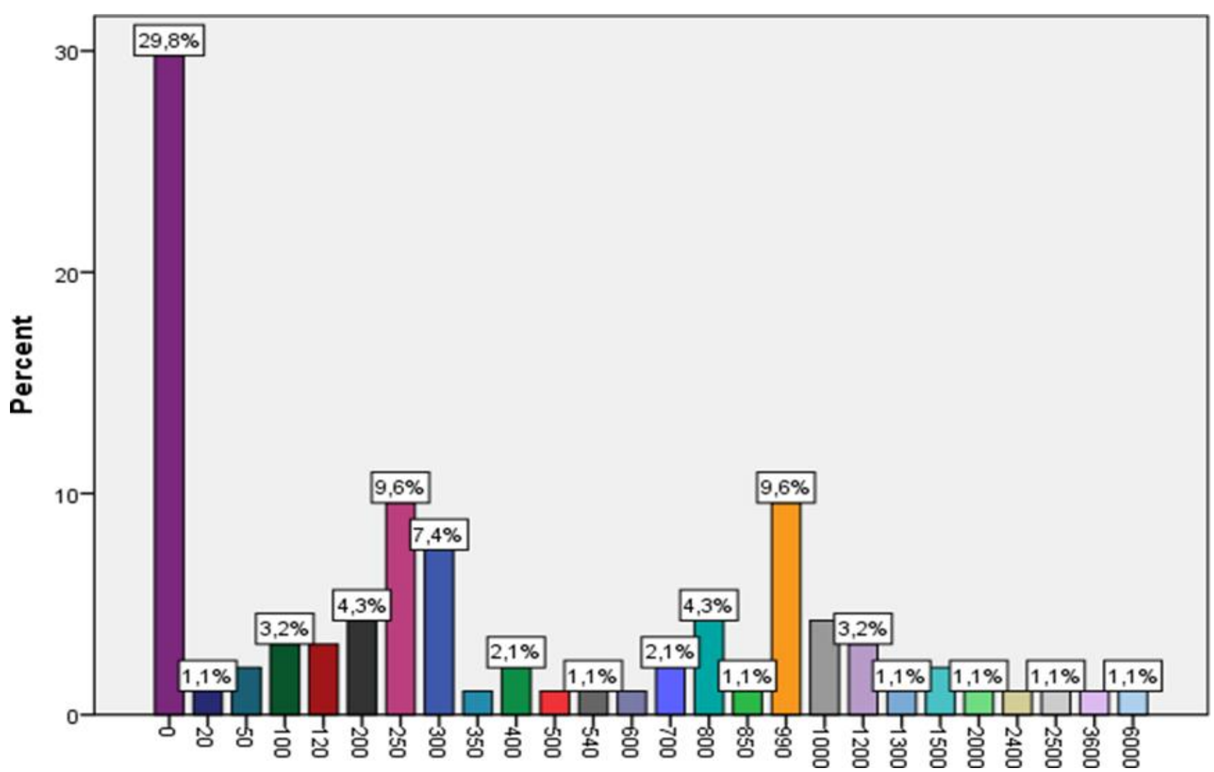


**Figure 14.** Cost of cleaning PV systems

### 4.4. Satisfaction of PV systems performance

The overall results demonstrated their high degree of satisfaction with the performance of the PV panels of their projects. More specifically, 89.41% were very satisfied, 7.06% were satisfied, and only five respondents (2.94%) were not satisfied with the operation efficiency of the PV systems. Finally, a very small percentage of 0.59% answered that they do not know.

The next question concerned the perceived factors that negatively affect the performance of PV panels. The interviewees collectively indicated that the main retarding factors are dust covering the panels and weather conditions, followed by the quality of the materials. Particular mention was made of the high temperature, which significantly reduces PV panel performance efficiency, especially in summer. In addition, the improper installation of the PV plant, which can also create shadows from surrounding elements, is considered an equally important negative parameter. Finally, respondents focused on poor maintenance and non-cleaning of the PV park, such as dirt, resulting in damage and grass in the surrounding area.

Then, PV Energy Producers were asked if they were considering renewing their type of PV panels and to what level of relative investment they were willing to reach. More than half of the producers answered negatively (54.29%), about 28.57% indicated that they intend to proceed with a change, while 14.2% responded that they would probably proceed with their renewal. Finally, a very small percentage of 2.857% answered that they did not know now.

Regarding the amount of investment of those considering renewing/replacing their PV panels, most producers responded that they are not in a position to know at the moment, and it will depend on the future contract they sign and the cost of the panels at that time. Those who were more specific gave an investment amount ranging between 20,000€ and 30,000€.

Then, PV energy producers were asked what percentage of PV panel performance improvement would be satisfactory to them in a hypothetical intervention and how many years of amortization of the investment such an intervention would be acceptable. The respondents considered a 5% and 10% performance increase satisfactory. However, several also believed such an intervention should improve the performance of PV panels much more. Regarding the estimated years for such an investment, most interviewees indicated a period between 2 and 5 years. More specifically, 30.68% of the sample indicated three years, 15.91% five years, and 10.23% two years.

### 4.5. Performance requirements of a new product

The next question was related to the interviewees' attitudes towards a potential product that would improve the performance of PV panels. The vast majority of the respondents showed a very positive attitude towards such a product. Indeed, some stated they would like to be informed further about it. However, very few producers reported their factor "cost" and how much it will be worth investing in such a product. The entire sample was then asked which of the following four features are most important to them to purchase a product that will improve the performance of PV panels. The features were: a) keeps the panels clean (self-cleaning, hydrophobic), b) can be installed easily, c) reduces the cost of maintenance and visits to the PV parks, and d) has anti-reflective properties (better absorption of sunlight). Across all companies, approximately three in ten (32.82%) reported that all four features are essential, keeping panels clean in combination with anti-reflective properties was reported by 22.56% of companies, while anti-reflective properties, as a full feature, from 16.41%.

PV electricity producers were asked if there is any other characteristic, apart from the four mentioned above, that they would like the specific product to have. Overall, a fair number of respondents cited the ability to reduce the temperature of PV panels as an important additional feature. Likewise, several respondents felt no further characteristics were required besides those mentioned above. In addition to the reduction in temperature, the producers also mentioned the increase in the panels' lifetime as an additional desirable feature. Both features are considered very important. The decrease in temperature fatally, brings about an increase in the efficiency of the panels. Thus, the possible increase in the PV lifetime is a vital element for PV producers, whose primary concern is the return on their investment.

Then, we asked about the form of the product that best satisfies their needs. Almost half of the respondents (48.5%) indicated a film, one in four (25%) thinks it would be better in a liquid spray, while 2% consider both forms acceptable (liquid spray and film). Finally, approximately one in four PV energy producers (24.5%) did not have an opinion.

The next question concerned the respondents' preference about the type of film, whether in a roll or ready-cut-in-pieces of specific dimensions. The majority indicated the ready-cut-in-pieces solution (48.22%). However, 31.47% stated they did not know the best option, while 20.3% indicated the roll option. In a further question to the group of producers, why they chose the specific product form, the producer companies pointed out the ease of use and better placement and application on PV panels.

## 5. Conclusion

The study findings indicated that producers operating in Greece have to face significant obstacles such as:

- *Bureaucracy and Licensing Issues:* There are significant obstacles related to the bureaucratic processes and delays associated with licensing procedures, which can hinder the timely establishment and operation of PV systems.
- *Frequent Changes in Regulations*: Producers face uncertainty due to frequent changes in laws and regulations by the government, which complicates planning and operational strategies.
- *Lack of Staffing in Competent Bodies*: Many producers reported a lack of adequate staffing in government bodies responsible for energy oversight, leading to inefficiencies in processing applications and support.
- *Saturated and Outdated Electricity Distribution Networks*: The existing distribution infrastructure is often not capable of accommodating new PV installations, leading to challenges in connecting to the grid.
- *Funding Limitations*: Many PV producers experience difficulties in securing funding for expansion or upgrades of their systems, which limits their capacity for growth.

These challenges contribute to a sense of stagnation among producers, although they maintain positive expectations towards the future due to increasing electricity demand and the commitment to green energy production in Greece. Nevertheless, their positive expectations for the future are based on the continuous increase in electricity demand, the scarcity of resources that plague our planet, climate change, and Greece's commitment to European standards for increasing green energy production.

Summarizing the study findings, most PV energy producers had been active for more than eight years at the time of the study. The average total installed capacity of the PV systems of the sample is 439.31 kW, while the average production efficiency is 1573.97 kWh. Moreover, a wide variation in their compensation rates was observed depending on their licensing year. In particular, early PV energy producers, before 2014, enjoyed significantly higher compensation prices. Most PV producers indicated that they concluded a contract with a sales price of up to EUR 0,33/kWh. Summarizing the attitudes and the PV energy producers' views on the sector in which they operate, most of them felt stagnation for a long time, which from 2018 onwards was replaced by an upward trend. They expect the future to increase the need for solar energy production in the country. Moreover, they see future developments and opportunities in energy storage and partnerships to create much larger PV parks.

Furthermore, the findings showed that PV energy producers primarily use polycrystalline panels with an expected lifetime of about 20 years. They usually contract external companies to conduct inspections, maintenance, and cleaning of the installations at a frequency of 2 to 6 times a year. They were satisfied with the performance of the PV installations and listed the main reasons for the decrease in performance. The most important ones were dust/dirt covering the panels, weather conditions, and the high temperature the panels developed during the summer.

The majority of the PV energy producers responded negatively to a question about their future intentions to renew the equipment of their installations. However, they had a positive attitude towards a product that, complementary to their existing installations, would allow them to obtain higher yields of at least 5% to 10%. Most were optimistic about the idea, but they worried about the cost of buying and using it, as it would have to be depreciated in 5 years at worst; otherwise, as they said, the benefit evaporates. It would benefit them if a product could keep the panels clean, be easy to install, reduce maintenance expenses, improve absorption of sunlight, increase their lifetime, and reduce the operating temperature. Finally, they considered that the best form the product could take would be in ready-made pieces of film.

The study showed that community practices significantly influence the maintenance of photovoltaic (PV) parks in several ways:

1. *Collaborative Maintenance Efforts*: Members of renewable energy communities often collaborate on maintenance activities, leading to more organized and resource-efficient upkeep of PV systems. This collective approach can enhance the overall performance of the parks and ensure that issues are addressed promptly.
2. *Knowledge Sharing*: Energy communities enable the sharing of best practices and experiences among members, which can lead to improved maintenance strategies. Producers can learn from one another about effective cleaning methods and technical care for the PV panels.
3. *Focus on Local Needs*: Community-based practices allow for a maintenance schedule that is tailored to local conditions, such as climate and environmental factors that may impact panel performance. This local knowledge can lead to more effective management of the PV parks.

4. *Increased Accountability*: Being part of a community can instill a sense of ownership and accountability among producers regarding the maintenance of PV systems. Members are more likely to invest time and resources in upkeep when they know it directly impacts their collective benefit.
5. *Resource Limitations*: While community practices have benefits, there may also be challenges, such as limited financial resources or expertise among members, which can hinder maintenance efforts. Communities must ensure they have the necessary skills and funds to maintain the PV parks effectively.

Overall, the practices within renewable energy communities can lead to more efficient and responsive maintenance of PV parks, enhancing their longevity and performance

## 6. Limitations – future research recommendations

The findings of the study are limited to the sample and country studied. Future research could replicate our study with larger samples and in various European countries to confirm current findings. Moreover, it is of great interest to study the energy communities, how their members communicate and collaborate to achieve common goals. Finally, the role of energy communities in the supply, pricing and policy making in the energy sector is another research direction we recommend for future studies.

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