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RENEWABLE ENERGY SOURCES:

AN INVESTIGATION OF SERVICE FIRMS SUPPORTING PHOTOVOLTAIC PARKS

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ABSTRACT

This article examines the services created and provided by photovoltaic (PV) service providers in the Renewable Energy Source (RES) sector and the challenges they encounter in this particular industry. The primary objective of this research was to investigate the provision of maintenance and cleaning services for photovoltaic (PV) systems, focusing on identifying optimal techniques for enhancing the efficiency of PV panels. To achieve these aims, a qualitative research methodology was used. Data was gathered by means of in-depth interviews conducted with a sample of 99 photovoltaic service providers throughout Greece. The findings indicate that the green energy industry is progressing, accompanied by the emergence of additional support services to enhance the effectiveness and functioning of renewable energy sources (RES). Nevertheless, the existing body of literature on the service sector is insufficient, highlighting the need for more study.

Keywords: Renewable Energy Sources; Green Energy; Photovoltaic Parks; Climate Change; Maintenance and Cleaning Services

INTRODUCTION

The pressing issue of global warming and the adverse environmental consequences linked to the use of fossil fuels for energy production have heightened the significance of transitioning to Renewable Energy Sources (RES) to an unprecedented degree in human history. Hence, the utilization of renewable energy sources (RES) has assumed a crucial role in the pursuit of global objectives for climate preservation. This is primarily attributed to its capacity to substantially mitigate greenhouse gas emissions and facilitate the widespread implementation of energy efficiency measures, which rely on more sustainable modes of energy generation. According to a recent research by the International Renewable Energy Agency[1], it is said that the accelerated deployment of renewable energy sources (RES) and improvements in energy efficiency have the potential to fulfill up to 90% of the environmental objectives outlined in the Paris accord. Solar energy is considered a prominent kind of Renewable Energy Source (RES), accounting for around 59% of the overall energy produced from RES in the year 2019, as reported by the International Energy Agency in 2020[2].

The primary objective of the European Green Deal is to enable Europe to achieve the status of being the first continent in the world to attain carbon neutrality by the year 2050. This very ambitious set of measures aims to facilitate the adoption of a sustainable green transition for both European people and enterprises, so enabling them to reap its benefits. The primary solution to address this problem is in reducing our dependence on fossil fuels, which are the primary contributor to climate change. The use of renewable energy is linked to a multitude of possible advantages, including the mitigation of greenhouse gas emissions, the promotion of energy supply diversification, and a less dependence on fossil fuel markets, including oil and gas. Renewable energy plays a substantial and increasingly prominent role within the energy system of the European Union, particularly in light of the ongoing energy crisis. The Europe 2020 plan established a target of attaining a minimum of 32% of gross final energy consumption derived from renewable sources by the year 2030. In the year 2020, the European Union consisting of 27 member states successfully attained a renewable energy consumption rate of 22%, which marks a significant increase from the 9.6% recorded in 2004. Renewable energy sources include a variety of sustainable options, such as wind power, solar power (including thermal, photovoltaic, and concentrated forms), hydro power, tidal power, geothermal energy, ambient heat harnessed via heat pumps, biofuels, and the renewable component of trash[3].

In the contemporary period, characterized by a growing need for energy consumption, individuals are becoming more reliant on the production of electrical power. The solar photovoltaic system is a dependable and environmentally friendly approach for power generation, achieved by the conversion of incoming solar radiation onto panels into electrical energy[4]. Consequently, substantial investments have been made on a global scale in the installation of photovoltaic (PV) systems. The photovoltaic (PV) industry is widely recognized as a field with significant potential for future development. The aforementioned phenomenon may be ascribed to the ongoing enhancement of photovoltaic (PV) characteristics' performance, the realization of economies of scale, and the implementation of national and international incentives aimed at attaining energy and environmental objectives. The cost of photovoltaic (PV) systems has been substantially lowered due to several variables, leading to a concurrent rise in global investor interest. Consequently, it can be seen that the annual worldwide growth rate had a substantial increase of 35% throughout the period spanning from 2010 to 2019, as reported by Philipps and Warmuth5. Furthermore, the total installed photovoltaic (PV) capacity exhibited a significant rise, reaching 627 GW by the conclusion of 2019, in contrast to the 100 GW recorded in 2012, as stated by the International Energy Agency1. Furthermore, it is worth noting that the global installations of newly implemented photovoltaic (PV) systems have consistently surpassed the 100GW mark for three consecutive years, as reported by the International Energy Agency in 2020.

China dominates the energy production market in terms of photovoltaic (PV) systems, accounting for a significant 66% share. Following China, the Central and East Asia area has a notable 18% stake in this sector. According to Philipps and Warmuth5, both the United States of America and Canada exhibit a shared 4% proportion, whereas Europe shows a 3% proportion. Nevertheless, despite Europe not being widely recognized as a prominent location for energy generation through photovoltaic (PV) systems, the integration of solar energy remains a fundamental component of the energy strategic policies implemented by its nations. The installation of photovoltaic (PV) systems with a power capacity of 16GW in the EU-29 in 2019, together with an additional investment of around 5GW in other European nations, is a testament to the significance of PV panel energy in Europe[2]. According to Philipps and Warmuth5, Europe accounted for 25% and 24% of the global photovoltaic (PV) production in 2018 and 2019, respectively. Furthermore, the EU-28 countries held a share of 20.5% in PV system installations by the end of 2019[5]. The total energy capacity of these installations was reported to be 131.3GW, as stated by the International Energy Agency[2].

This study seeks to analyze the services produced and provided by photovoltaic (PV) service providers in the renewable energy sector (RES). Additionally, it tries to highlight the challenges encountered by these providers in delivering their services. The primary objective of this research was to investigate the provision of maintenance and cleaning services for photovoltaic (PV) systems, with a focus on identifying optimal methods to enhance the efficiency of PV panels.

Research Findings on Solar Energy and Maintenance Practices of Solar Panels in Various Countries

Solar photovoltaic (PV) technology has emerged as a critical component of the global renewable energy transition, with research demonstrating that proper maintenance practices are essential for maximizing system performance and longevity[6]. Recent studies indicate that dust accumulation can reduce solar panel efficiency by up to 30%, making regular cleaning essential for sustained performance[7]. The global solar panel operation and maintenance market is projected to grow from USD 15.73 billion in 2025 to USD 32.63 billion by 2034, representing a compound annual growth rate of 8.44%[8]. Comprehensive research on solar panel performance reveals significant variations in degradation rates across different technologies and environmental conditions[9]. A 25-year study of monocrystalline silicon PV modules in Egypt found that maximum power decreased by an average of 23.3% over time, with degradation rates varying for different electrical parameters[10]. Research indicates that the median solar panel degradation rate is approximately 0.5% per year, though this can range from 0.2% to 1.28% annually depending on environmental conditions and module technology[11].

Advanced research utilizing emotional artificial neural networks (EANN) has shown that energy efficiency can vary from 10.34% to 14.00% during operational hours, with an average efficiency of 13.6%[12]. Studies demonstrate that many modules still perform above 80% of their original power rating after 25 years, suggesting potential for extended operational lifespans beyond traditional 25-year warranties[13]. Furthermore, research by Aurora Solar and KWh Analytics reveals that solar systems installed since 2015 have broadly underperformed expectations by 7% to 15%[14]. Key factors contributing to energy losses include soiling effects, which can cause 5% losses in areas with long dry seasons, with additional 1-2% losses in regions with frequent dust deposits. Incident angle modifier effects typically contribute to 3-4.5% losses, while temperature effects and equipment mismatches further impact system performance[14].

Regional Maintenance Practices and Approaches.

Asian nations have developed unique maintenance approaches that blend traditional methods with modern technology[15]. In China, maintenance practices are influenced by diverse climatic conditions, with regions prone to industrial pollution employing combinations of robotic cleaning and community-based manual labor[15]. Japan emphasizes precision and sustainability, utilizing automated cleaning systems while maintaining traditional methods in rural areas where technology access is limited. The cultural emphasis on meticulousness ensures high attention to detail in maintenance procedures[15].

European countries have established themselves as pioneers in sustainable solar maintenance, with Germany, the Netherlands, and Scandinavian nations setting industry standards[15],[16]. SolarPower Europe recently launched updated Operation & Maintenance Best Practice Guidelines Version 6.0, which includes revised guidance on maintenance, data management, electrical safety, and common tests and inspections[16]. German practices showcase automated cleaning systems that reduce water usage while employing environmentally-friendly detergents[15]. Scandinavian nations utilize biodegradable cleaning agents and leverage natural resources like rainwater for panel washing[15]. Regional maintenance practices in Africa and the Middle East have adapted to unique climatic challenges including intense heat, water scarcity, and desert dust[15]. South Africa has adopted waterless cleaning technologies using brushes and air-based systems to preserve scarce water resources[15]. The United Arab Emirates employs state-of-the-art robotic cleaners and specialized coatings that minimize dust adhesion, reducing cleaning frequency requirements[15].

The International Energy Agency Photovoltaic Power System Programme (IEA-PVPS) has established standardized guidelines for operation and maintenance programs across different climate zones[17]. These guidelines provide climate-specific O&M programs for moderate, hot and dry, hot and humid, and high-elevation desert areas[17]. The IEC 62446-2:2020 standard describes preventive, corrective, and performance-related maintenance requirements for grid-connected PV systems[17]. Research on water consumption in PV panel cleaning demonstrates significant opportunities for resource optimization[18]. Studies comparing cleaning methods show that specialized cleaning solutions can reduce water usage by up to 97.7% compared to water-only cleaning approaches. The frequency of cleaning varies by location, with panels requiring cleaning every 6-12 months under normal conditions, but potentially every 3-4 months in high-soiling environments[18].

Economic analysis suggests that improving annual degradation rates from 0.5% to 0.2% could provide cost benefits of up to 12 cents per watt for utility installations19. Maintenance becomes approximately 33% more valuable when considering extended system lifetimes beyond traditional 25-year period[19]. The integration of artificial intelligence and predictive maintenance technologies is increasingly important for optimizing system performance and reducing operational costs. In sum, research demonstrates that effective maintenance practices are crucial for maximizing solar energy system performance across diverse global environments. Regional variations in climate, resources, and cultural approaches have led to innovative maintenance solutions that balance efficiency, sustainability, and economic viability. Continued research and standardization efforts will be essential for supporting the growing global solar energy infrastructure.

METHODOLOGY

The context of the study

The energy industry in Greece is widely recognized as a crucial component of the country's economy, characterized by substantial and ongoing investments in renewable energy sources (RES) over the years. Greece has endeavored to align itself with worldwide climate protection measures in order to effectively mitigate environmental degradation and address the growing energy needs. In relation to solar energy, many other elements, including geographical location, climate, and soil variety, significantly contribute to the generation of solar energy inside a given nation. Hence, investments in photovoltaic (PV) systems are seeing a consistent upward trajectory. The energy generated by photovoltaic (PV) systems in Greece accounted for 8.1% of the total energy production in 2019, surpassing the European Union's average of 4.9% and the global average of 3%. This places Greece in the fifth position globally, alongside Australia, and behind Honduras (14.8%), Israel (8.7%), Germany (8.6%), and Chile (8.5%) according to data from the International Energy Agency[2].

Based on data provided by the Greek association of PV companies in 2020, it was observed that the cumulative power output of interconnected photovoltaic (PV) systems in Greece amounted to 160.02MW in 2019. These systems were categorized into PV parks, self-production through net-metering, and PV systems falling under a special program. Consequently, the overall installed capacity of PV systems in Greece reached 2.83GW. In comparison to the year 2018, there was a notable rise of 371.2% in the installation of new interconnected photovoltaic (PV) systems. Additionally, the cumulative energy generation from PV sources in 2019 amounted to 3.96 terawatt-hours (TWh), as reported by the European Commission in 20203. The future prospects of photovoltaic (PV) systems in Greece are highly regarded as favorable. In recent years, there has been a reversal of the previous inactivity in photovoltaic (PV) investments, which was mostly attributed to the suspension of licensing for new PV projects during the period of 2012-2014 and the lack of a consistent legal framework. Specifically, there has been a consistent upward trend in the adoption of self-production projects using net-metering, particularly those of short to medium-range, throughout the period from 2015 to 2019. Moreover, the national energy and climate plan in Greece, which was concluded in 2019 and aligns with the environmental and energy strategy of the European Union and the Paris agreement, provides a comprehensive outline of the country's strategic policy, in line with the prevailing global inclination towards substantial investments and the expansion of photovoltaic system installations. Hence, the establishment of photovoltaic (PV) system energy infrastructures is seen as an essential and unidirectional choice (Figure 1)[20].

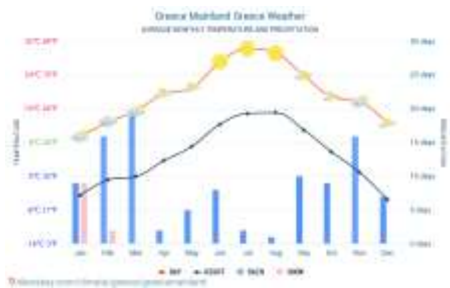

Figure 1. The average yearly temperatures and precipitation in Greece

The Greek government has set a target of achieving a total power generation capacity of 3.9GW from photovoltaic (PV) systems by the conclusion of 2022. Furthermore, they have outlined a long-term objective of attaining a capacity of 7.7GW by the conclusion of 2030, with intermediate milestones of 5.3GW in 2025 and 6.3GW in 2027. During the same timeframe, it is projected that the yearly energy generation would amount to 6.3TWh by 2022, with a long-term objective of achieving 12.1TWh by 2030. Therefore, it is anticipated that the contribution of photovoltaic (PV) systems to the overall energy generation in the nation would increase from 8.1% in 2019 to 20.7% in 2030, with intermediate projections of 11.3% in 2022 and 17.7% in 2027[20].

Research design

In order to achieve these aims, a qualitative research technique was used. The empirical component of the study used a qualitative exploratory technique, using in-depth interviews with open-ended questions to collect data. Interviews were chosen as the preferred method of data collection due to its ability to assist researchers in identifying essential themes, while also providing respondents with the freedom to express their thoughts, provide novel ideas, and voice any concerns they may have. Furthermore, prior primary research has shown the utility of conducting in-depth interviews to examine obstacles to investments in renewable energy sources (RES).

The formulation of the questionnaire was carried out using a three-stage process. During the first phase, the process of searching for and gathering prior empirical research pertaining to photovoltaic (PV) systems was conducted. The present study conducted a comprehensive literature analysis to identify and gather relevant questionnaire questions from previous research studies[21,22,23,24,25]. During the second phase, the process of formulating questionnaire questions occurred, with their subsequent categorization into 13 distinct classifications. Subsequently, a reclassification of the questionnaire items was undertaken with the objective of developing distinct questionnaires for the three target groups identified in the study: i) firms engaged in photovoltaic (PV) installation and construction, ii) firms engaged in PV installation, construction, and maintenance services, and iii) firms engaged in PV installation, construction, PV equipment supply, and maintenance services. During the final phase, the questionnaire underwent testing with two owners of photovoltaic parks, after which necessary refinements were implemented.

Sample

The first step involved compiling a comprehensive roster of 753 photovoltaic (PV) companies. This was accomplished by gathering data from reputable sources such as the Greek federation of PV electricity producer associations (https://www.pospief.gr/), PV companies association (https://helapco.gr/lista-melwn/), and the catalog of the Ministry of Environment, Energy and Climate Change (http://www.cres.gr/pvcatalog/DoIt). The selection process aimed to ensure a well-rounded sample that adequately represented each prefecture within the Greek territory. The list included of professionals in the field of photovoltaic (PV) technology, including PV installers, PV system builders, PV equipment suppliers, and companies specializing in maintenance services. A correspondence was sent to every firm, soliciting their involvement in the research. A total of 204 photovoltaic (PV) enterprises expressed their willingness to participate in the interview process. The interviews were performed using online platforms or telephone conversations, depending upon the respondents' availability. Out of the total, 105 organizations were identified as producers of photovoltaic (PV) power, while 99 companies were categorized as suppliers of PV maintenance, cleaning, and consultancy services.

RESULTS

The findings of the research revealed the existence of six distinct categories of services that have been formed within the photovoltaic (PV) industry. These categories include contract/maintenance services, contract/consulting services, contract/maintenance/PV equipment suppliers, PV equipment suppliers, contract/PV equipment suppliers, and consultancy services. Subsequently, we inquired about the perspectives of service providers about the photovoltaic (PV) industry, including its current state and future prospects. Regarding the present circumstances, it is noteworthy that the market saw a notable upswing prior to 2018. However, in recent years, there has been a discernible downturn primarily attributable to the industry's reliance on a limited number of prominent enterprises, who wield significant influence over pricing mechanisms (characteristic of an oligopoly) and often exhibit delays in remitting payments. In relation to prospective prospects within the industry, participants express a consideration for energy storage, expansive initiatives such as photovoltaic parks, maintenance and installation services, as well as the implementation of net metering. According to the respondents, it is anticipated that over the course of the next five years, there will be a notable surge in energy generation using photovoltaic (PV) systems. Furthermore, the sector is expected to undergo substantial advancements, ultimately aligning with the established European benchmarks for the production of environmentally sustainable energy. The primary challenges often recognized in the advancement of the industry are bureaucratic processes and licensing delays, frequent legislative modifications, limited access to bank funding, the marginalization of small-scale producers, issues pertaining to distribution networks, and a dearth of skilled personnel.

The observations pertaining to the lifespan of PV panels are equally noteworthy. The mean lifetime of the panels is around 21.32 years, which closely aligns with the manufacturers' typical warranty period of 20-25 years. In relation to the chosen photovoltaic (PV) technology among Greek firms, Monocrystalline and Polycrystalline PV panels are the most favored options. In addition, it is worth noting that over the last three years, Monocrystalline PV Panels have emerged as the dominant technology in the Greek Market. Greek companies choose to avoid the use of Thin Film PV panels due to their poorer efficiency in hot climates, such as that of Greece. This preference is based on logical reasoning. Another notable discovery is that suppliers of PV maintenance and cleaning services often do not engage in the sale of maintenance and cleaning products. The survey respondents indicated that maintenance supplies accounted for 5.6% of the products sold, while cleaning goods accounted for 1.9% of the total sales.

Furthermore, it is noteworthy that contractors, maintainers, and suppliers express a high level of satisfaction with the photovoltaic (PV) equipment they install or sell. Additionally, they exhibit similarly high levels of client satisfaction, with a satisfaction percentage of 100%. An further noteworthy discovery from the current study with significant practical value pertains to the perceived elements that have a detrimental impact on the performance of photovoltaic (PV) panels. Based on the results of the study, the primary inhibiting factors identified are the accumulation of dust on the solar panels and adverse weather conditions, with the quality of the materials being a secondary consideration. Particular emphasis was placed on the elevated temperature, which notably diminishes the efficiency of PV panels, particularly during the summer season. Furthermore, the inadequate placement of the photovoltaic (PV) plant, which may result in the casting of shadows by nearby objects, is seen as an equally significant and unfavorable factor. Ultimately, the participants directed their attention towards concerns pertaining to inadequate upkeep and neglectful sanitation practices inside the photovoltaic (PV) park. These problems included the presence of dirt, consequential damages, and the growth of grass in the vicinity.

Regarding the verification procedures conducted by firms for each client, a significant proportion of the respondents said that they execute checks biannually (37.1%), followed by annual inspections (22.6%), while a mere 6.5% reported conducting daily checks. Regarding maintenance and cleaning, 54% of the sample engages in maintenance activities, while 30.2% conduct both maintenance and cleaning tasks. Photovoltaic (PV) service companies often provide maintenance services only (54%), cleaning services alone (4.8%), or a combination of both (30.2%). Regarding the maintenance procedures for photovoltaic (PV) systems, the participants expressed the importance of conducting visual inspections to assess the condition of various components such as cables, panels, corrosion, and cameras. Additionally, they emphasized the need for electrical inspections to ensure proper functioning, using thermal cameras to detect any anomalies, and ensuring the inverter operates efficiently. Furthermore, respondents highlighted the significance of regular cleaning activities, which may include washing by spraying or mowing. According to the respondents, a majority of them (46.9%) said that they do all the required maintenance tasks. On the other hand, a significant proportion (32.8%) stated that they engage in optical-electrical-sprinkling-grass cutting activities.

Regarding the cleaning methods employed, it is observed that 26.5% of individuals utilize brushes in conjunction with deionized water. Additionally, 19.6% solely rely on deionized water for cleaning purposes, while 18.6% engage in simple washing techniques. Conversely, 11.8% do not employ any specific cleaning methods. A smaller proportion of 6.9%, opt for telescopic brushes, whereas 4.9% utilize either a crawler or a crawler equipped with brushes and deionized water. Furthermore, 8.8% employ alternative methods such as robotic systems, while 2.9% possess no knowledge regarding the cleaning methods used. Furthermore, a significant proportion of the service providers exhibit a reluctance to modify their maintenance practices. Nevertheless, they have shown a keenness to explore approaches for deionizing water prior to doing the cleaning of photovoltaic (PV) panels (refer to Table 1).

Table 1 Maintenance and cleaning methods of PV parks

PV maintenance methods	Percentage	PV cleaning methods	Percentage
Visual inspection (cable inspection, broken panel, rust, camera), Electrical inspection (operation, thermal camera, and efficient operation of the inverter), and Cleaning (washing - spraying or grass mowing).	54%	Use brushes and deionized water.	26.5%
		Use deionized water	19.6%
		Simple washing	18.6%
		Does not use anything for cleaning	11.8%
		Use telescopic brushes	6.9%
		Use crawler or crawler with brushes and deionized water	4.9%
		Other methods (robotic systems)	8.8%
		Did not know	2.9%

PV operation and performance checks by maintenance service providers Yes No	85,9% 14,1%	Average cost of deionized machine: Average cost of brushes:	500 Euro 300 Euro

The involvement of an increasing number of enterprises in the domain of photovoltaic (PV) station maintenance has significant importance. Based on the above research results, it can be inferred that organizations operating in the photovoltaic (PV) industry hold the belief that there would be a rise in business prospects pertaining to PV station maintenance inside the forthcoming years. Regarding the maintenance procedures, it is seen that 46.9% of the maintenance businesses do all the required maintenance tasks, while 32.8% of the companies conduct visual inspection, electrical inspection, and cleaning inspection. Another intriguing discovery pertains to the essential cost per kilowatt for photovoltaic station upkeep. A significant proportion of participants (46.5%) said that the cost per kilowatt is within the range of €6 per KW. As a consequence, the whole standard maintenance expenditure for a 500KW photovoltaic (PV) facility amounts to €3,000. A considerable proportion of individuals hold the belief that the rational cost per kilowatt (kw) is €10, resulting in an estimated overall maintenance cost of €5,000 for a 500KW photovoltaic (PV) station (as seen in Figures 2 and 3).

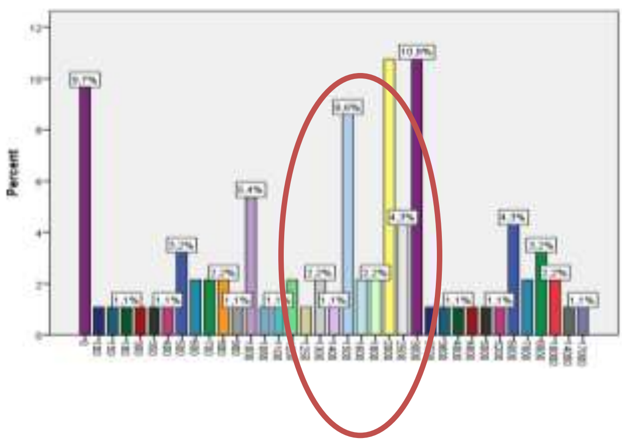

Figure 2. Average PV park maintenance cost (in Euro)

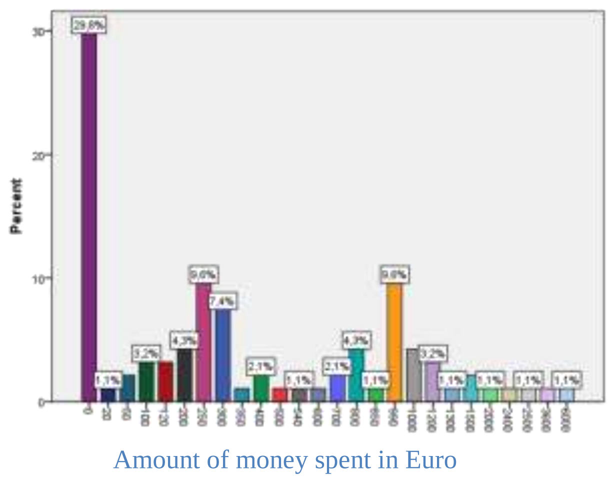

Figure 3. Average cost of cleaning the PV parks (in Euro)

CONCLUSION

Over the course of the next five years, there is a projected surge in energy generation using photovoltaic (PV) systems, accompanied by substantial advancements in the field. These developments are anticipated to align with the European criteria for the production of environmentally sustainable energy. Potential prospects in the industry include several avenues, including energy storage, large-scale projects such as photovoltaic parks, maintenance operations, installation services, and the implementation of net metering systems. Regarding the primary challenges encountered by the energy sector, the investigation has identified several key issues. These include bureaucratic hurdles, difficulties in energy distribution, frequent legislative changes, inadequate staffing, delays in permit issuance, overburdened networks, marginalization of small-scale producers, breach of contractual agreements, insufficient bank financing, and a dearth of information.

Within the photovoltaic (PV) industry, the primary services that have been identified are maintenance, cleaning, and consultancy. The frequency of maintenance and cleaning services for PV panels is rather low, often occurring once or twice per year. This limited provision might be attributed to the "amateur approach" used by numerous owners and the associated costs involved. Additionally, there seems to be a reluctance to embrace novel approaches to maintenance and cleaning practices, which further reinforces the risk-averse cultural tendencies seen in Greece. In summary, the green energy industry is seeing growth, accompanied by the emergence of new ancillary services aimed at enhancing the efficiency and functioning of renewable energy sources (RES). Nevertheless, the existing body of literature in the service sector is insufficient, hence necessitating further study to be conducted.

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