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An economic investigation on the consumption of the photovoltaic panels in Algeria

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Abstract :

This study discusses the renewable energies sector in Algeria. It aims at assessing the customers' choices of the photovoltaic panels types. It compares between the consumption of the monocrystalline, polycrystalline and Thin-film technology panels in Algeria. Then, it investigates the factors which influence the customers' selection of a certain panel over the other. For this, this research relies on a quantitative approach, using field investigation and surveying as tools to collect data. More, it uses an analytic method to depict and analyze the customers' preference of a given type of PV panels.

This research work concludes that the polycrystalline PV type is the most used in Algeria by public and private customers. It ended into the fact that most of the customers' selection is influenced by budgetary factors more than the technical ones.

Keywords:

Green economy; Algeria; Photovoltaic panels; consumption; quantitative.

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1. INTRODUCTION:

The renewable energies sector became one of the growing technological and economic sectors in the 21th century. Different factors contribute to its development. To illustrate with, climate changes stirred massive voices that called for reducing carbon dioxide emissions emerging from factories and human activities. More, economic experts recommended the involvement of clean energies, such as the Aeolian and solar energies, as sustainable solutions for prominent shortages in oil supplies. They combined the economic growth with sustainable energies.

1.1. Statement of the Problem: There are three main different types of the PVs on the Algerian market, these are: the monocrystalline, the polycrystalline and the Thin-Film technology. This study discerns the criteria on which the customers -private and public- prefer to install a certain type of photovoltaic panels in Algeria.

1.2. Research Question: This paper answers the following question: On which bases do the Algerian customers select a type of photovoltaic over another?

1.3. Hypotheses: This research works on the following hypotheses. It suggests that the polycrystalline panels are the most consumed in Algeria because of two main factors; these are: technical and budgetary. In addition, it assumes that the selection was subject to budgetary considerations more than technical ones.

1.4. Significance of the Study: The present research paper investigates the status of the green economic projects in Algeria. It sheds light on the renewable energy market, particularly the consumption of the solar energy equipment in Algeria.

1.5. Objectives of the Study: This study purposes to discuss the renewable energies in Algeria; particularly the consumption of the photovoltaic panels. It aims at identifying the PV panels type that is most consumed in Algeria; then, it investigates the factors that influence the customers' selection of the given panels type.

1.6. methodology of the Study: This research uses the quantitative and qualitative approaches to assess the consumption of the photovoltaic panels in Algeria. It uses field investigation and surveys to collect data about the customers' choices and preferences of the PVs. The field investigation involves public and private enterprises. Moreover, this research paper uses a comparative method to identify the convergences and divergences between the monocrystalline, polycrystalline and Thin-film PVs. Then, it relies on an analytic approach to identify and study the customers' bases on which they select the PVs basing on the data collected through the surveys and the field investigation.

1.7. previous researches: To answer the problematic, this research work relies on a variety of recent studies and official reports. For instance, to define the Algerian photovoltaic program, this research relies on official reports of the Commission for the Renewable Energies and Energy Efficiency such as the Energetic Transition in Algeria

(2020) to delineate Algeria's roadmap of the photovoltaic installations and statistics. In addition, it uses recent studies to depict and assess the development of the photovoltaic energy consumption in Algeria such as Naziha Boulkedra and Nabila Lakhal's Photovoltaic: An Idea, an Achievement and an Economic Impact in Algeria (2021), Hamiti Dalila and Bouzadi- Daouda Sultana's The Algerian Energy Transition Strategy in Line with the Renewable Energy Development (2021) and Souhila Eddrief-Cherifi Renewable Energy in Algeria: What an Alternative to Fossil Energies? (2012).

1.8. Organization of the Study: This research paper is divided into three main thematic parts. Firstly, it defines the general aspects of the renewable energies sector in Algeria. Secondly, it investigates the types of photovoltaic panels available on the Algerian marketplace. Thirdly, it discusses and evaluates the customers' bases of the consumption of the solar panels.

2. A historical overview of the solar energy:

The sun constituted a source of power for several ancient civilizations since the dawn of history. Different cultures and peoples approached the sun from various perspectives; some worshipped it and others relied on its energy for agricultural and thermal purposes. During the Neolithic Age that spanned from 5000 BC to 2000 BC, the Stonehenge monument was constructed with an alignment with the sun. It was used as a worshipping space that allowed the sunlight during winter to enter to the inside (History. Alberta Ca, 2022). Historical records show that the ancient Egyptian civilization used extensively the solar energy to heat their shelters. They constructed their houses with thermal techniques so that they store the sun heat along the daytime; then, the walls released the heat during the night. This thermal aspect helped the house-keepers to enjoy warm nights (clean choice energy.com, 2018). Then, by the 3rd century BC, the Romans and the Greeks used mirrors as tools to reflect the sunlight. The burning mirrors lightened torches which were used for religious ceremonies in both civilizations (energysage.com, 2018).

Later, in the mid-18th century, Horace Benedict de Saussure (1740-1799), a Swiss physicist, invented the first solar energy collector, named hot box (Szabo, 2017, p 3). Then, by the 19th century, the industrial revolution stirred up innovative ideas and projects amongst engineers and scientists. Their inventions were economically and industrially oriented. To illustrate with, W. Adams invented the sun collector that is an oven with octagonal reflectors made from glass mirrors. The latter concentrated the sunlight to a box to allow the cooking of the food inside the pot (Szabo, 2017, p4). The Swedish-American John Ericsson (1803-1889) invented the Sterling engine that used solar energy collected by a reflector (Szabo, 2017, p5). Besides, the discovery of the photovoltaic effect constituted a turning point to the manufacturing of the solar energy

equipment and industry as a whole. Etymologically, the term photovoltaic is composed of two Greek words: *phos* and *volt*, which mean light and the electro-motive force unit. Historically speaking, Alexandre-Edmond Becquerel (1820-1891) -a French physicist- invented the photovoltaic cell when he was only 19 years old. Conducting his experiments at his father's laboratory, Becquerel illuminated silver chloride that he put inside an acidic solution. He noticed voltage on the platinum electrodes (Szabo, 2017, p6).

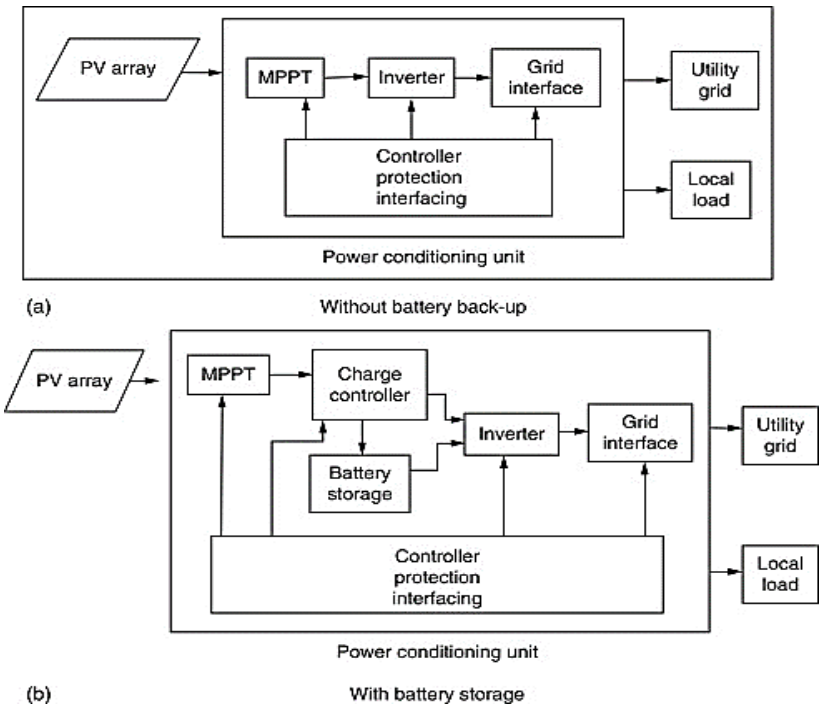
3. The Available Photovoltaic Panels in the Algerian Marketplace: Technical and Manufacturing Aspects:

This section discusses the technical aspects and the manufacturing process of a photovoltaic panel; it exposes its main components and system. Then, it demonstrates the three major types of PV panels.

3.1 Definition of Solar Photovoltaic System:

The Photovoltaic system is a sustainable solution for both energy production and consumption. It functions basing on a set of six fundamental components. The PV system converts solar energy that is collected through the cells into a direct current. Then, the DC transforms into alternating current (AC)- throughout an inverter- to be exploited by the users (Off Grid Solar Power Simplified, 2012, p 26). The following diagram demonstrates the PV solar systems with their components.

Figure N°01: Diagram of the Photovoltaic Systems



Source: El Chaar, 2011

Besides, as shown in figure 1, the solar PV system consists of the following components:

- The solar PV array
- A charge controller (optional)
- A battery bank (optional)
- An inverter
- A utility meter
- An electric grid

2.2 Types of the Photovoltaic Panels:

There are three main types of the photovoltaic panels sold in Algeria; these are: the Monocrystalline panels, the Polycrystalline panels and thin-film panels.

A. Monocrystalline Panels and the Polycrystalline Panels

Generally speaking, the Monocrystalline has high efficiency and aesthetic characteristics. The Polycrystalline panels are cheaper than the Monocrystalline. However, they have lower performance characteristics.

The cells of both the Monocrystalline and the Polycrystalline modules are made from silicon wafers. The latter have a rectangular shape and are covered with a glass sheet. They differ in terms of the composition of the silicon. The former's cells are cut from a single pure crystal of silicon. Nevertheless, the latter's cells are made from fragments of silicon crystals melted in a mold before being cut to wafers. Because of the interactions between light and the pure silicon crystal, the Monocrystalline panels have black color. More, as the light reflects off the silicon fragments of the Polycrystalline, the panel has a blue color (see figure 2). Both panels (mono and poly) have a variety of colors for frames and back sheets (Mertens, 2014, p99).

Besides, the Monocrystalline are primarily produced through the Czochralski process, CZ. In brief, the process consists of the following main steps:

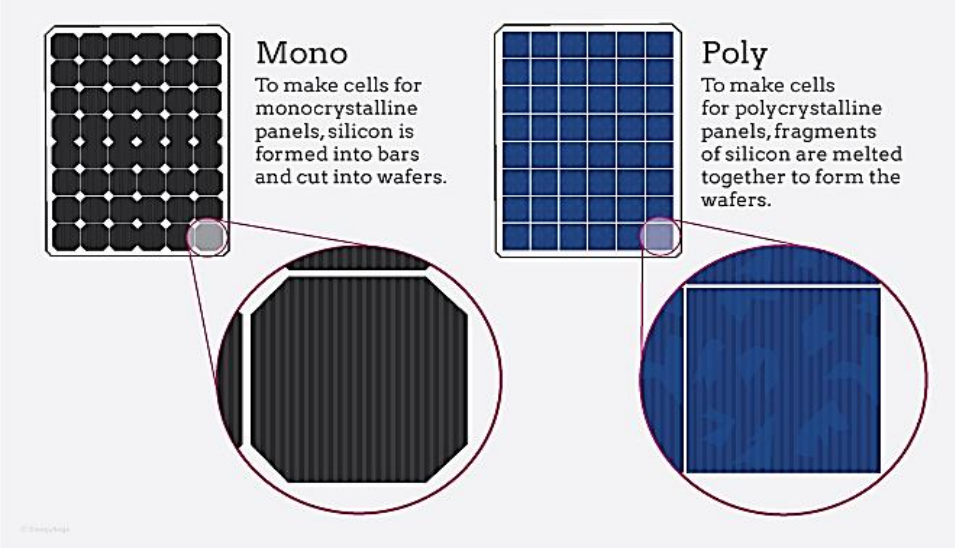
- Polysilicon pieces are melted at a temperature of 1450 °C.
- A seed crystal is placed at the melted polysilicon.
- By the exposure of the melt onto a slight rotation, the silicon attached to the metal rod and crystalizes.

The ingot (Monocrystalline silicon rod) is manufactured by adjusting its thickness according to the principle of the float-zone process (Mertens, 2014, p 101). Moreover, the production of the Polycrystalline cells (SI) is performing than that of the Monocrystalline. The process starts by pouring the silicon solution into the molds that are divided into slabs. Then, after the liquid became solid, the crystal structures are

formed with different dimensions (Cotar et al., 2012, p8). Overall, our comparison between the mono and polycrystalline panels ends into the following results:

1. **Cost:** the polycrystalline panels are cheaper than the monocrystalline.
2. **Lifespan**: both types have a lifespan of more than 25 years
3. **Efficiency:** the monocrystalline is highly performing than the polycrystalline.
4. **Aesthetics:** the monocrystalline has a black color while the polycrystalline inclines towards blue color
5. **Manufacturing**: unlike the polycrystalline, the monocrystalline has a complicated manufacturing process and generates more waste of silicon (Ash, 2022).

Figure 2: Monocrystalline and Polycrystalline Panels



Source : ases.org, 2021

For instance, the Algerian factory Milltech manufactures both the monocrystalline and the polycrystalline types. The company is established in Chelghoum El Aid in the willaya of Mila in 2004. It works in both the telecommunication field and the renewable energies. The factory disposes a unit of manufacturing specialized in the photovoltaic modules. According to its official statements, Milltech produces 200 MW per year through which it is classified the 2nd producer of the photovoltaic panels in the African continent. Moreover, Milltech produces a range of solar panels with different technical aspects such as the standard module SIRAJ, the glass-glass module CHAFAQ, half-cell module DIA, and the bifacial module NIBRAS (Milltech, 2022). The company manufactures both the mono and the polycrystalline modules using the models above (see annexes N°01 and 02).

B. Thin-Film Technology

Thin-film panels are portable and flexible. They are also lightweight and have attractive aesthetic aspects (see figure 3). Nevertheless, they have the lowest performance rate than the mono and polycrystalline panels. They are composed from different materials. For instance, there are several types of T.F panels such as the CdTe the Cadmium Telluride and CIGS, Copper Indium Gallium Selenide. T.F panels are thinner than the mono and polycrystalline panels based on their materials and they have blue and blackish colors. They are made on the basis of pilling thin layers of photosensitive sheets on glass, plastic or a stainless metal. For this, T. F panels are cheaper than the mono and polycrystalline ones (Cotar et al. 2012, p9). Practically speaking, T. F modules are classified into four commercialized types; these are: Amorphous silicon (a-SI), Cadmium Tellurium (CdTe), Copper Indium Gallium Selenide (CIS, CIGS) and Thermo sensitive solar cells and other organ cells (DSC) (Kirchartz et al. 2016, p32).

Figure N°02: Thin-Film Solar Panel (left) and Rigid Solar Panel (right)

Source: hebesolar.com, 2022

4. An overview of Renewable Energies in Algeria

In Algeria, the Renewable Energies is a promising sector. The government set projects for the energetic transition that became an economic necessity. For the developing countries, the sector aims at supplying their industries and households' growing demands. However, for oil exporters, the energetic transition ET purposes to exploit oil and gas rents to diversify the energetic supply. The ET also involves the implementation of carbon pricing as well (Hamiti and Bouzadi-Daoud, 2021, p 598). The

Algerian government issued a program to install 15000 MW by 2035 (GIZ, 2021, p8). the Algerian program of the renewable energy production marked a significant development from 2009 to 2017. In 2009, it marked only 0.001 % of the overall production. Then, it reached 4.979 % by 2017 (Eddrief-Cherifi, 2012, p386).

For instance, on December 23th 2021, the Algerian Ministry of Energetic Transition and Renewable Energies METRE established Solar 1000 MW project. It purposed to install solar PV centrals of 50 to 300 MWc across Algeria. The Algerian company SHAEMS, Spa under the supervision of the METRE took in charge the different phases of the PV projects with all their stages in conventions with the investors starting from the retreat of the term-books to the evaluation and the verification of the offers (GIZ, 2021, p15). According to official statistics, the production of the PV energy from 2010 to 2014 rated from 0 to 1 GWh. Then, from 2015 to 2016, it increased sharply to 205 GWh. By 2017, it increased slightly into 374 GWh and then reached 545 GWh in 2019 (GIZ, 2021, p8). The table below demonstrates a number of Algerian ministries that installed photovoltaic panels such as the National Ministry of Defense that installed 3859 KWc, the Ministry of Interior MICLAT reached 9156 KWc and the Ministry of Commerce with only 27 KWc (CEREFE, 2020, p55).

Table N°01: Statement sheet of the different sectors in Algeria with PV Installations off-grid

National Ministry of Defense	**3859 KWc**
Ministry of Interior MICLAT	**9146 KWc**
Ministry of Energy	**344 KWc**
Ministry of Agriculture and Rural Development	**4197 KWc**
Ministry of Post and Telecommunication	**937 KWc**
Ministry of Habitation, Urbanism and City	**256 KWc**
Ministry of Tourism, Craft and Family work	**612 KWc**
Ministry of Culture	**20 KWc**
Ministry of Transportation and Public works	**1721 KWc**
Ministry of Water Resources	**244 KWc**
Ministry of Commerce	**27 KWc**
Ministry of Education and Professional Training	**12 KWc**

Source: CEREFE p55.

The Algerian government supported the PV energy projects by launching a program for the RE that would be maintained from 2015 to 2030. It involved the installation of 13 575 MWc of photovoltaics (Boulkedra and Lakhal, 2021, p1199). From 2011 to 2017,

only 354 MW capacity was established in Algeria. Later, by 2018, a project aiming at realizing 4050 MW was launched by the Algerian government. Then, the overall PV capacity would probably increase to reach 800 MWc by 2020. It would be raised to 200 MWc per year from 2021 to 2030 (Boulkedra and Lakhal , 2021, p1199). For this, our research emphases the investment in photovoltaic solar panels in Algeria. It aims at revealing the types of the installed modules in both public and private sectors and uncovers the criteria on which the customers select a certain type over the others for installation. The following section demonstrates our conducted filed investigation and discusses the obtained results.

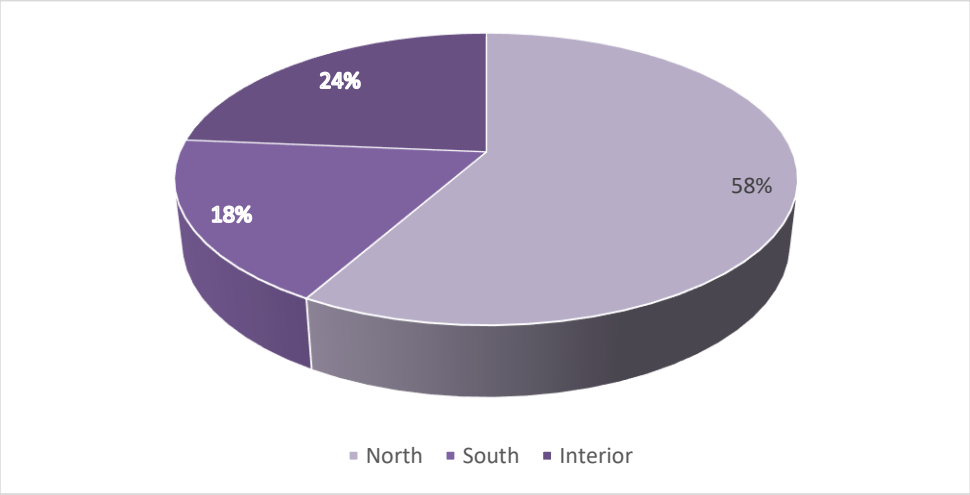
5. Results

This section assesses the consumption of the monocrystalline, polycrystalline and Thin-film PV panels in Algeria through the quantitative approach. It relies on the field investigation and survey to collect the necessary data to calculate the rate of the consumption of each PV type in Algeria as a step to determine the factors which influence the choices of the customers. The latter are categorized into public and private enterprises.

The present investigation was realized through a survey and a field investigation; it involved official Algerian organizations pertaining to the Renewable Energy sector, public and private enterprises, and experts. The challenge that we faced in our investigation is the limited number of specialized enterprises in photovoltaics. Thus, we contacted them via telephone and email. For the experts and the professionals, we delivered our questionnaire to university researchers and PhD students from different universities in Algeria. Further, we got feedback from non-governmental organizations too.

Practically speaking, our questionnaire tends to answer the following questions: What is the most installed PV panel type in Algeria? On which criteria do the customers select their PV panels? Are they satisfied with their use of PV panels as sustainable energy suppliers? The following graphs demonstrate the divisions of our samples in accordance to their regions. The overall number of the collected samples equals 165 from three principle regions in Algeria: the north, south and the interior sector. According to the graphs, the participants in the north side of Algeria exceeded 58%. However, we got only 18.18% samples from the south. Moreover, our investigation reported 23.63% samples from the interior region.

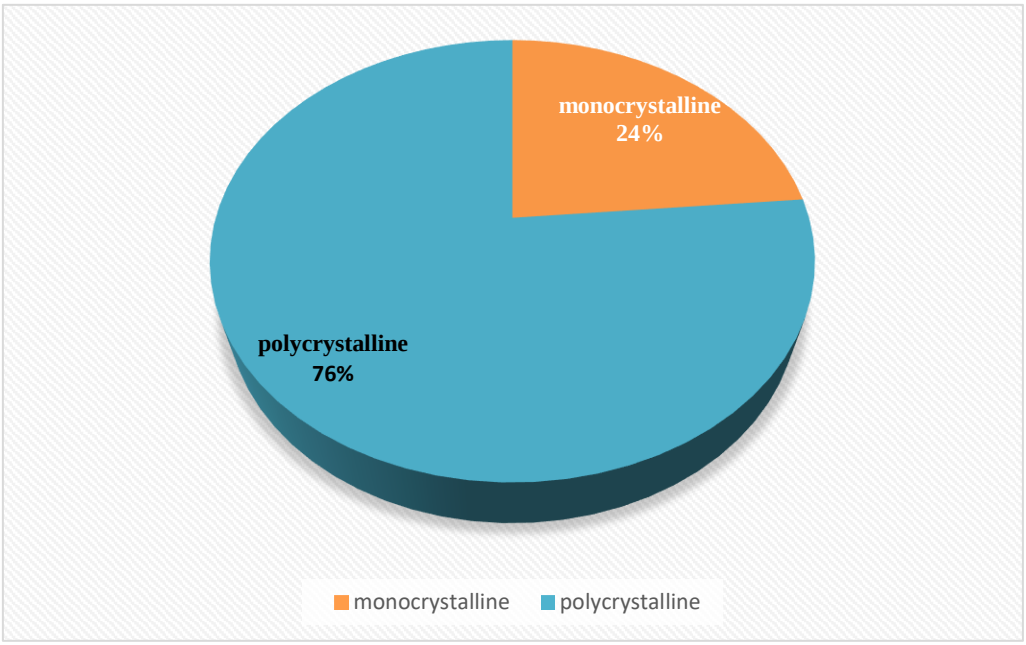
Figure N°03: Regional Divisions of the Study Samples



Source: the data were calculated by the author

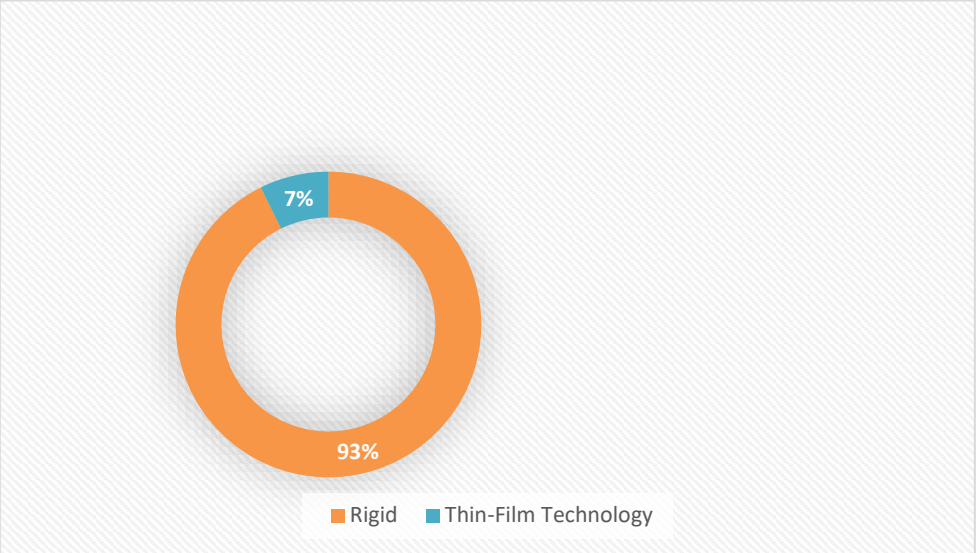
The graphic charts below demonstrate our findings of the field investigation that we have conducted in 2022. Besides, our field investigation ended into the following results. From the 165 samples, 23.6% claimed that the Algerian customers prefer installing monocrystalline photovoltaic panels, on one hand. On the other hand, our investigation concluded that more than 76% of the samples asserted that the Algerian customers prefer using the polycrystalline panels.

Figure N°04: Types of the installed PV panels in Algeria



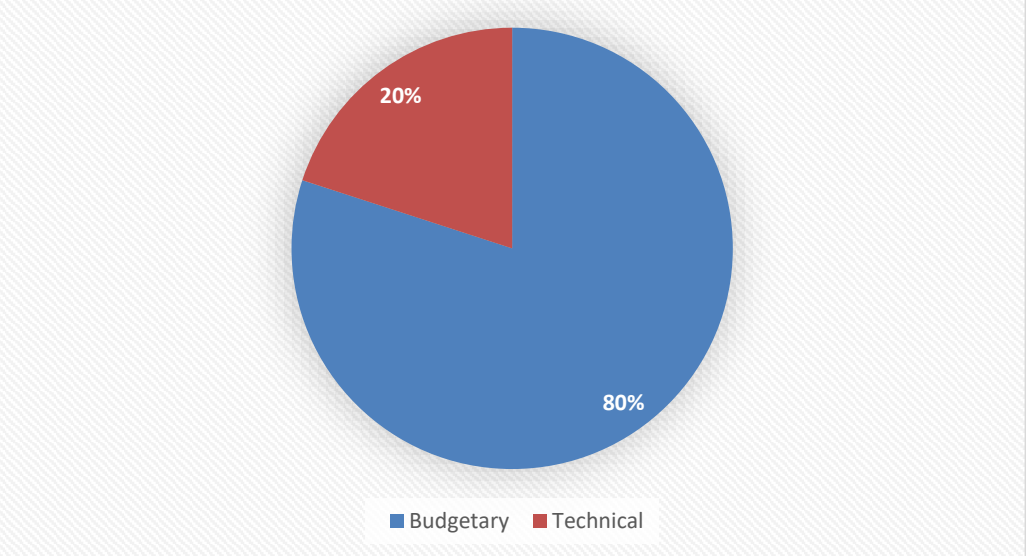
Source: the data were calculated by the author.

Figure N°05: The Most installed PV models in Algeria



Source: the data were calculated by the author

Figure N°06: PV Panels criteria of selection by Algerian customers



Source: the data were calculated by the author

Moreover, the present field investigation revealed that 92.7% of the installed PV panels in Algeria are rigid models whereas only 7.3% are flexible. Besides, our study uncovered that 80% of the customers select the polycrystalline PV panels for installation referring to budgetary considerations compared to 20% who preferred the technical characteristics of the panels.

6. Discussion:

Our research ended into the result that the polycrystalline photovoltaic panels are the most consumed panels than the monocrystalline and the Thin-film PVs in Algeria. The Algerian customers select this type for their technical aspects as they are more performing and more solid than those of the Thin-film PVs. For budgetary considerations, the customers view that the polycrystalline are cheaper than the monocrystalline. For instance, the costs per Watt for a mono PV panel stands between $0.50 and $0.80 whereas for poly PV is between $0.40 and $0.50 (Levesque, 2022). In the course of our investigation, an important number of experts emphasized that the poly PVs are more installed in the Algerian South because of their resistance to higher temperatures. On the aesthetic level, the poly PVs have an attractive design than the monocrystalline with their bluish color (see fig.2). In this sense, the Algerian market disposes of a variety of solar panels thanks to the important number of Algerian factories that produce and sell the photovoltaic equipment. For example, there several manufacturers of solar panels such as Condor in Bourdj Bou Ariredj, Aures Solaire in Batna, Milltech project in Milla (Takouleu, 2021). It is important to note that the Algerian government is launching new projects for the manufacturing of solar energy equipment in other regions in Algeria like Ouregla. This strategy tends to supply the national market with products "made in Algeria" to reduce the heavy importation bills of the equipment.

However, our investigation concluded also that the Thin-film PVs are the less demanded in Algeria with a less share on the national and international markets. In addition, they were classified as less performing too. For this, there is no significant demand on them on marketplace.

Practically speaking, there different PV panels that are developed with innovative designs and characteristics by the Thin-film technology. For example, the Cooper Indium Gallium Selenide panels are classified by worldwide experts as the most promising thin-film technology for several reasons. First, they absorb light 10-100 times than silicon cells. Second, their production process requires less raw materials. Third, the CIGS are categorized efficient with 22.8% compared to c-SI crystalline silicon. Above all, they showed higher radiation resistance as well (Senthil and Kalaiselvi, 2019, p 208). These panels are designed to be installed in places where rigid monocrystalline and polycrystalline panels cannot be installed such as: rocky places, spaces with very high temperatures, old or weak roofs of houses, industrial firms or on movable devices. They are light-weight and resistant to high temperatures like those in the African deserts. Finally, the manufacturing of the CIGS has low costs along the production process and the raw materials purchases as well compared to other PV panels. Unfortunately, the production equipment is expensive and generates supplementary expenditures on their

maintenance too. This constitutes a challenging fact for the renewable energy industry as a whole.

The growing demand on the photovoltaic panels impelled Thin-film PV factories to innovate new designs with higher efficiency more performing to compete with the polycrystalline and the monocrystalline PVs. Even though they constitute the least rate in the PVs market, their technology is significantly providing the Renewable Energy market with innovative panels that compete with both the monocrystalline and the polycrystalline PVs. Needless to say, Algeria constitutes a profitable and a promising marketplace for this technology, despite the negative results we got from our field investigation.

7. CONCLUSION:

This research work discussed the Renewable Energy sector in Algeria. It investigated the most installed photovoltaic panels; it compared between three types of PV panels: monocrystalline, polycrystalline and Thin-film PVs on the technical and manufacturing levels too. As a step to determine the most sold photovoltaic panels in Algeria, this study used quantitative and qualitative approaches. It used a field investigation and surveys and collected data from official organizations, public and private enterprises and technicians. It revealed that the polycrystalline photovoltaic panels are the most installed among public and private institutions and companies as well with 76.4% compared to 23.6% of monocrystalline. More, it revealed that only 7.3% of customers prefer Thin-film PVs whereas 92.7% installed rigid photovoltaic panels. Further, out investigation ended into the main factors that influence the Algerians to choose the polycrystalline panels; these are: the technical aspects of the PVs as they are solid and more performing than the Thin-film PVs and aesthetically more attractive compared to the two types. The second factor is financial; it is the most significant criteria with 80% compared to 20% for the technical factors. This study revealed that the polycrystalline are cheaper than the monocrystalline though they both have the same lifespan of 25 years. Despite the fact that the Thin-film PVs are less demanded on the Algerian and even on the international markets, this study demonstrated that there are big investments in China, Europe and the USA that tend to develop this type to provide the international market with innovative photovoltaic panels using Thin-film technology and developing solar panels more performing than the monocrystalline and the polycrystalline. This demonstrates that the Thin-film PVS constitutes a promising industrial and economic future that would influence the Algerian market at the very near future.

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9. Annexes:

Annex N°01: PV panels Made in Algeria: SIRAJ 5BB MONO-PERC 60 CELL /320W

MECHANICAL SPECIFICATION	
Module dimension	1649*992*35 mm
Number of cells	60
Weight	18kg
Cell type	PERC Monocrystallines M2 cells
Glass	3,2mm thickness fully tempered
Backsheet	White backsheet (1500V)
Frame	Aluminium
Jbox	IP67, 3 diodes
Cables	4mm2 (1500V)
Connector	QC4.10 (1500V)
TEMPERATURE CHARACTERISTICS	
Temperature coefficient of PMAX	-0.390% / °C
Temperature coefficient of VOC	-0.300% / °C
Temperature coefficient of ISC	0.060% / °C
Nominal Operating Cell Temperature (NOTC)	45°C

Source: Milltech, 2022

Annex N°02: PV panels Made in Algeria: SIRAJ 5BB POLY 60 CELL /275W

MECHANICAL SPECIFICATION	
Module dimension	1649*992*40 mm
Number of cells	60
Weight	18kg
Cell type	Polycrystallines M2 cells
Glass	3,2mm thickness fully tempered
Backsheet	White backsheet (1500V)
Frame	Aluminium
Jbox	IP67, 3 diodes
Cables	4mm2 (1500V)
Connector	QC4.10 (1500V)
TEMPERATURE CHARACTERISTICS	
Temperature coefficient of PMAX	-0.406% / °C
Temperature coefficient of VOC	-0.308% / °C
Temperature coefficient of ISC	0.057% / °C
Nominal Operating Cell Temperature (NOTC)	45°C

Source: Milltech, 2022