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D10.9 PROGRESS REPORT ON CHOICE OF PHOTOVOLTAICS TECHNOLOGY

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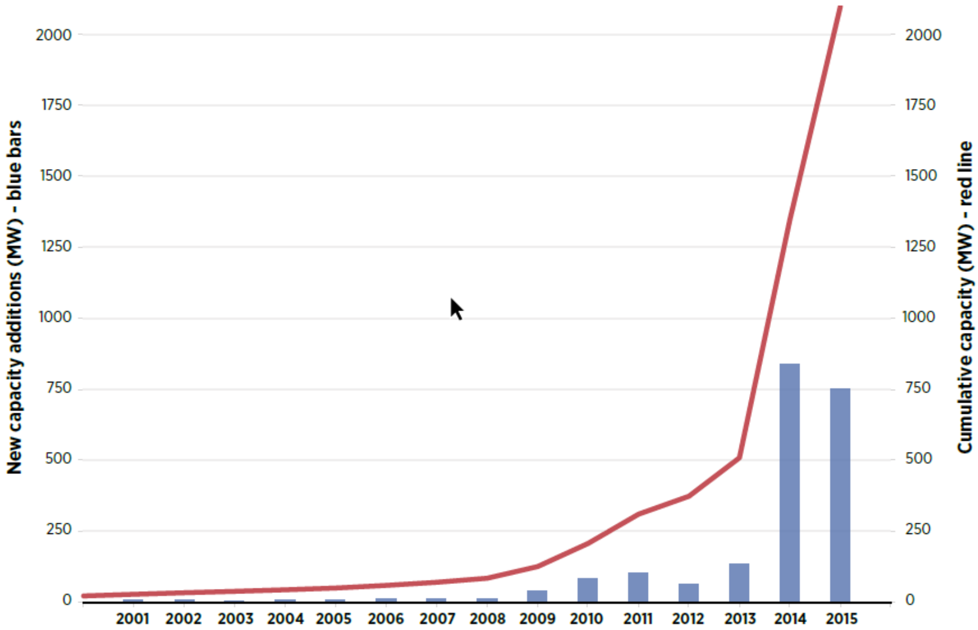
2. Introduction

The Long-term Europe-Africa Partnership on Renewable Energy (LEAP-RE) programme is co-funded by the European Union (EU) under Horizon 2020 and aims to increase the use of renewable energy via a well-balanced set of research, demonstration, and technology transfer projects in both continents. The Productive Use in Rural African Markets using Standalone Solar (PURAMS) project aims to develop a standalone solar cooking appliance (cooker), to address the challenges caused by traditional cooking methods and faced by rural communities in Africa. The use of a renewable source of energy (that is solar power) to power the cooker is a vital component of this project

2.1 Literature Review

2.1.1 Solar PV Technology and cooking

The African continent receives the most amount of sunshine over the course of the year compared to all the other continents on the globe.. Statistics show that the total installed solar PV capacity has more than quadrupled between the years of 2013 to 2015 (Michael Taylor, 2016). With solar PV panels becoming less and less expensive to the ordinary consumer we are seeing a steady increase in off-grid electricity supply Installed costs for power generated by utility-scale solar PV projects in Africa have decreased as much as 61 per cent since 2012 to as low as USD 1.30 per watt in Africa (Michael Taylor, 2016). This puts it in a propitious position to harness solar power to power the continent especially when it comes to clean cooking.
The second goal in the seventeen Sustainable Development Goals is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. This is a colossal



task as the logistics required to facilitate production, transportation and distribution of foodstuff is deeply complex to navigate, stemming from the inaccessibility of infrastructure, such as roads and railways, the steep rate of population growth, the severe changes in climate, lack of arable land to till and hostile political landscapes.

Figure SEQ Figure * ARABIC 1: Africa's total cumulative installed capacity of solar PV, 2000-2015. Source:Solar PV in Africa CITATION Mic16 \l 2057 (Michael Taylor, 2016)

In sub-Saharan Africa, the prevalence of moderate or severe food insecurity is 59.5% of the population according to the World Bank (Prevalence of moderate or severe food insecurity in the population, 2019). This figure does not consider the third part of the second SDG:

improved nutrition for all. Some of the major fuels used to cook meals in both rural and urban communities also have the downside of denaturing the essential nutrients in the foods thus reducing the overall nutritional value of the meal.

In Task 10.1 of PURAMS WP10: Resource assessment and business model development, a data collection exercise was undertaken in Rwanda and Kenya to assess the type of meals prepared by the rural populace and the types of cooking fuels used (António Couto, 2022) It was found that in these rural communities bio-mass fuels such as firewood and charcoal are the main cooking fuels used. These fuels are obtained by deforestation of surrounding vegetation and in case of charcoal causes more air pollution to manufacture it.

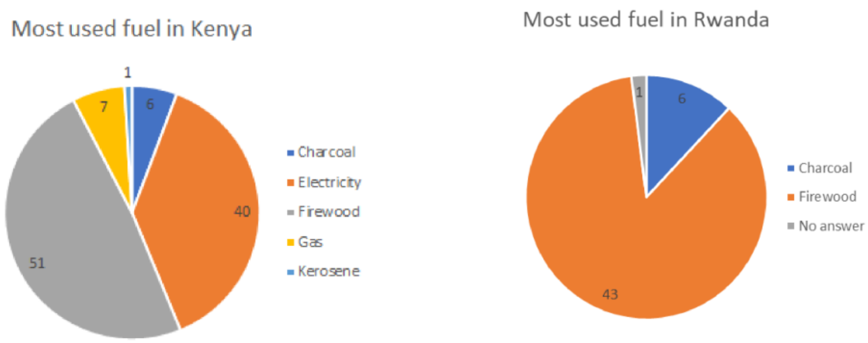


Figure 2: Pie charts illustrating the common cooking fuels used in Kenya and Rwanda Source: Standalone solar cooking appliance design metrics (António Couto, 2022)

Use of biomass generates particulate matter causing indoor air pollution which has been linked to adverse health outcomes especially pulmonary diseases. Examples of these

diseases are pneumonia, asthma, stroke, chronic obstructive pulmonary disease, and lung cancer. Domestic duties including cooking often fall on women thus they endure the most of these health issues and complications. Young children spend most of their time with women hence are also exposed to household air pollution which has been shown to double the risk of childhood pneumonia. The WHO ascribes 45% of all pneumonia deaths in children less than 5 years old and 28% of all adult pneumonia deaths worldwide to household air pollution. Additionally, gathering firewood and splitting it are labour-intensive processes which can cause injury and strain
Therewithal the cooker will be safe as it is designed with multiple safety features and is more efficient compared to regular cooking instruments.

2.1.2 Solar PV as a technology

Industrially produced silicon photovoltaic solar modules can achieve efficiencies of up to 22% (Office of Energy Efficiency and Renewable Energy, 2015). This is a rather dismal value as compared to nuclear or fossil fuels but because of the abundance of energy from the sun and the relative ease to convert solar energy to electrical energy, solar power is the safest and most eco-friendly solution to powering the continent.

Silicon (Si) is the most used material for solar cells fabrication. Found in sand (SiO2), Si is the basis of the electronic industry. The process of fabrication of solar cells starts with purification of sand at increasing temperatures up to 1400 C. Then follows the building of ingots. At last, comes the part of building of the electric device (solar cell). Products of the process are: (i) Single crystalline silicon, if all steps of purification are followed and (ii) Multicrystalline or Polycrystalline silicon, if some purification steps are avoided. Solar cells are put together into modules at manufacturing factory. At applications levels solar modules are put together in a way to produce the required voltage and current for the load to be powered. These units are called solar panels.

The advantages of using silicon for solar cells fabrication are as follows:

- Sand is a plentiful material;
- Si is one of the best understood elements in the periodic table of elements;
- Availability of mature technology from the silicon electronics industry.

Apart from advantages, there are disadvantages as well, some of which can be characterized as follows:

- High energy consumptions during the purification processes for both technologies, but less for multicrystalline Si;
- High materials consumption for both technologies.

Some semiconductor materials enable deposition of thin layers of these materials on low-cost substrates, like glass. One of such materials is amorphous silicon (a-Si). Other thin film solar cells are those of copper indium diselenide ($CuInSe_2$, usually abbreviated to CIS) and cadmium telluride (CdTe), among others. Advantages of thin film solar cells are:

- Less energy consumption as lower temperatures are involved in preparation of thin films as compared to crystalline silicon;
- Less materials consumption (100 times less than in crystalline technology);

As disadvantages of the thin film solar technology, it is to consider lower efficiencies as compared to crystalline silicon.

3 Comparative Assessment of the Different Solar Cells Technologies

The technology of thin film solar cells is still at a stage of development [1, 2, 3]. Only amorphous silicon has reached the stage of industrial production. Nevertheless, a-si cells are more appropriate for indoors consumer products like calculators, electronic watches, among others, due to a rapid degradation in a context of high-level intensity of light. A-si is not for professional applications so far. In view of that, it makes sense to compare both technologies of crystalline silicon.

Monocrystalline solar cells pros and cons can be detailed in the following way [1, 2, 3]:

- **Pros:** (i) highly efficient at producing energy (15 to 20% of efficiency); (ii) panels require less space; (iii) better heat tolerance.
- **Cons:** (i) expensive; (ii) less sustainable production methods.

Polycrystalline solar cells pros and cons are as follows [1, 2, 3]:

- **Pros:** (i) less expensive than monocrystalline panels; (ii) lifespan comparable to that of monocrystalline panels yet at a lower cost.
- **Cons:** (i) panels require more space; (ii) less efficient at producing energy (13-15% of efficiencies); (iii) less sustainable production methods; (iv) less heat tolerance.

The factors affecting the efficiency of solar photovoltaic panels are (Vidyanandan, 2017):

  - Degradation of PV Module
  - Variation in Solar Radiation
  - Module Temperature
  - Fill-Factor
  - Parasitic Resistances
  - Shading
  - Potential Induced Degradation
  - PV Module Orientation and Tilt Angle
  - Soiling

- **Degradation of PV Module**

Solar PV panels are sold with a warranty from manufacturers. In the documentation sold with the panels the estimated lifetime of the panels is present, usually twenty-five to thirty years. Solar panels degrade faster in their first ten years compared to their second ten years. This is due to mechanisms such as exposure to UV radiation which causes the crystalline silicon oxide on the surface of the panel to form a layer of boron dioxide that reduces its efficiency, mechanical wear and tear due to the environment and potential-induced degradation (Rodríguez, 2021)

- **Variation in Solar Radiation**

Insolation is the power per unit area received from the Sun in the form of electromagnetic radiation. The intensity of insolation affects the short circuit current, the open circuit voltage and the power produced by the panel. Insolation maps are often used to plan the deployment of solar systems all around the world.

- **Module Temperature**

Solar PV modules are made using semiconductor materials which are susceptible to changes in temperature. This is due to the thermal energy yielded from the temperature changes increases the internal carrier recombination rates thus reducing the voltage in the module, lowering the total power output

- **Fill-Factor**

Fill-factor (FF) is the ratio of the maximum power to the product of open circuit voltage and short circuit voltage. It is a measure of the “squareness” of a solar cell and is the area of the largest rectangle that can fit in an IV curve.

- **Parasitic Resistances**

These are the series and shunt resistances present in solar cells (as well as other electrical machines/ devices) that reduce the efficiency of the solar cells by dissipating power in the resistances. Power loss is usually I^2R

- **Shading**

Shading, as the name suggests is when one or more cells in the PV module are blocked from receiving sunlight. Even one cell being under shade can reduce the output of the whole string of cells, due to the cells being configured in series and as the current must be the same in each cell the current of the shaded cell is zero, hence all the cells have no current flowing in them

- **Potential Induced Degradation**

Dr K.V. Vidyanandan defines potential induced degradation as "a performance degradation mechanism in PV systems due to stray currents, leading to gradual loss of power up to 30% or more. (Vidyanandan, 2017)" This occurs many years after installation of the system.

- **PV Module Orientation and Tilt Angle**

For maximum energy output from the PV cells, the module needs to be always facing the direction of the sun so that the incident rays of the sun will be perpendicular to the cells. This is not always possible as the sun's path shifts slightly depending on the time of year and day.

- **Soiling**

Soiling is defined as the accumulation of dirt, snow, and other particulate matter on the PV module. This accumulation eventually forms a layer on the module and hence reduces the amount of light falling on the cells of the module. Soiling in some cases can result in an annual power loss of 5-17% (Vidyanandan, 2017).] The power loss incurred by this mechanism can be mitigated by use of multiple means as discussed below

2.1.3 The Challenge and Existing Solutions

It is obvious to note that soiling is a major issue when it comes to the sub-Saharan region of the continent whereby majority of the rural markets exists in pseudo-urban conditions, and this brings about an interesting profile of soiling mechanisms whereby the dirt and smoke emitted by the market is compounded by the biological waste often deposited by birds and other flying animals. Thus, the transmittance of the solar photovoltaic system is affected and hence the efficiency of the solar panel (up to 17% per year) is not up to par. This is what we plan to tackle.

2.1.3.1 Strategies to reduce soiling

- **Module Tilt angle**

The angle at which a solar PV module is oriented with respect to the ground/ surface it is mounted on. A study conducted in Rabat Morocco by Soukaina Medaghri Alaoui, Salima El Ayane, Dounia Dahlioui and Abdelfettah Barhdadi found that the soiling deposits on two panels placed at zero degrees and forty-five degrees were quite different (Soukaina Medaghri Alaoui, 2018). The deposition on the panel tilted at forty-five degrees was more homogeneous compared to that of the panel tilted at zero degrees. The zero-degree tilted panel had areas on the panel that had large soiling deposits whilst others had none.

by Soukaina Medaghri Alaoui et al explains this phenomenon (Soukaina Medaghri Alaoui, 2018):

For the sample of 45°, the water drops formed by the condensation of water particles under the effect of humidity, they transport dust thanks to the gravity, and they leave thereafter traces of their path, which are indicated in the Fig. 6. For the sample of 0°, the water drops deposited by the moisture effect remain on the glass surface and then after drying, the drop circumference presents an obstacle for the soils transported by wind. Which favour consequently its accumulation.

They also investigated the transmittance loss of the panels in question and found that whilst both had losses, the forty-five-degree angle panel had a loss of 0.84% whilst that of the zero-degree panel had a loss of 3%

- **Super Hydrophobic Films**

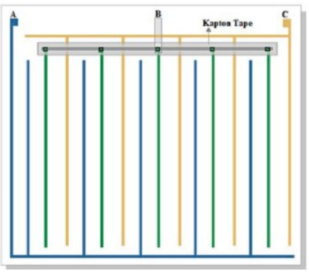
Hydrophobic film coatings are solar PV panel coatings that form barriers to the spreading of the water droplets which forces them to stay in their spherical shape due to surface tension. This makes the droplets carry any deposition to the bottom of the module under the effect of gravity. These coatings also have anti-corrosion and anti-icing properties making them a great method to mitigating soiling

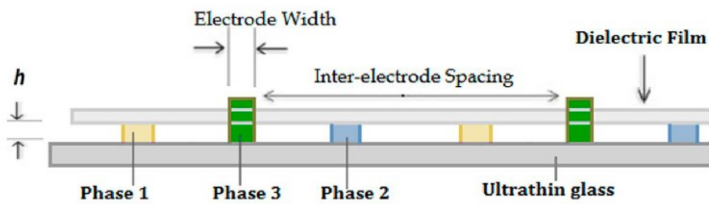
- **Super Hydrophilic Films**

These are film coatings that spread out the water droplets turning them into a thin film that allows light to pass through them and through the process of photocatalysis chemically decomposes any dirt or pollutant on the surface of the module (Srijita Nundy, 2020). They are typically made of titanium dioxide or silicon dioxide. They are more efficient than super hydrophobic films

- **Electro Dynamic Screen (EDS)**

An electrodynamic screen is a set of transparent parallel electrodes, embedded in a transparent dielectric film (Mazumder, 2013). It is described as a self-cleaning technology that does not require manual labour, water or moving parts to function. Their energy draw is almost negligible. Below is a schematic diagram of their parallel electrode geometry (Annie Rabi Bernard, 2018).





- **Site Selection**

Selecting a site that is conducive to the deployment of a solar system is paramount. Areas that receive sunlight with little or no shade are ideal, as are areas that are far from roads, agricultural activities, and industries.

2.1.3.2 Approaches to remove soiling

- **Water-dependent cleaning**

The most common way of cleaning solar PV panels is by manual using a brush and water. This is economically unfeasible in areas with little to no water access.

- **Electrostatic Cleaning**
  - Kawamoto and Shibata (2015) developed in the laboratory an electrostatic cleaning technique that uses single-phase high voltage and wire electrodes to airborne the dust particles, which will drift downwards in response to the gravitational forces of the inclined surface (A. Younis, 2022)

- **Mechanised Cleaning/Automated Cleaning**

There are multiple ways of automating cleaning of panels: using timed sprinklers, wash panels, mechanical arms and robots. In *A review on cleaning mechanism of solar photovoltaic panel* (Patil, 2017) the authors discuss various cleaning robots and wash panels on the market such as the GEKKO Solar Farm, PvSpin, HECTOR from Heliostat and many others.

3. Methodology

3.1 Assessment of existing PV technologies

Research began in M7 with a detailed bibliographic analysis of the commercially available solar panels in the market. The panels were sorted out from the point of view of the PV manufacturer as the technical features. They can be essentially classified into three types of solar panels according to the complexity of the material employed in their fabrication.
Thus, the three categories are monocrystalline, polycrystalline, and thin film amorphous solar panels. The type of solar cells that are used to manufacture the solar panels identify the type of panel. The material composition of the solar cells entails different characteristics for the panels, which makes them particularly suited for a market niche. The most common panels in the market are monocrystalline and polycrystalline.
The selected PV technology for this project is the 24V monocrystalline solar panels with a maximum nominal power output of about 450W. These PV panels are the best choice for isolated self-consumption installations. The average price for these PV panels oscillates between 180-220 €. The supplier normally offers a 25-year power guarantee.
The previous type of PV panel is selected due a combination of the different characteristics:

- Ease of cleaning, the silicon cells are covered with a glass that can be simply washed with water. Further studies will be carried out on this issue.
- Moderate cost with respect to the flexible solar panels
- Simplicity in the installation and connection with the electrical components as inverters or charge controllers.
- PV panels with the highest performance
- This type of solar panels are the best sellers, so they are easily accessible in the locations of piloting

We have selected two international suppliers for PV panels:

- **AutoSolar**. This is an online shop that provide a large selection of solar panels, solar batteries (both stationary and monoblock batteries), inverters and charge regulators (https://autosolar.es/). They are located in Spain, being a domestic supplier for the UCO partner which can accelerates the delivery of the PV components needed for the fabrication of the PV solar cooker.

An example of the selected PV panel offered by Autosolar is: 450W 24V Monocrystalline PERC ERA Solar Panel offering a high energy collection capacity for its small size (2094x1038x40mm, 24 kg). Highly recommended for large installations. It is made up of PERC monocrystalline silicon cells, so it obtains greater performance than a conventional solar panel. The PERC ERA 450W 24V Monocrystalline Solar Panel offers the best efficiency of the 24V solar panel range, producing a maximum current of 10.85A.

- **TP Energy**. Shenzhen Topsky Energy Co. Ltd was established in 1998 and has been engaged in the photovoltaic industry for more than ten years (http://www.topskyenergy.com/). TP Energy is currently headquartered located in Shenzhen, Guangdong, China. Mainly committed to the production, development and sales of solar cells, solar module, lightweight solar panel, customized small and mini solar panels and other application products. Products are exported to global markets, including North America, South America, Europe, Southeast Asia, Middle East, Africa. This company can provide the panels needed for fabricating the PV cooking prototypes ensembled by the SU partner.

An example of the PV panels supplied by TP Energy is the 144 Half Cells 440W-460W Monocrystalline Solar Panel. The main technical features of this panel are maximum power output of 440-460 W, size of 2108x1048x35mm and a weight of 23.5 kg.

3.2The Solution

After extensively reviewing the possible methods of preventing and cleaning soiling we decided to with EDS, super hydrophilic coatings and manual hand washing. This is because the women who will use this system are laymen and having complicated cleaning mechanisms would burden them and create a barrier to using the system.
The super hydrophilic films will make it easier for them to clean as it breaks down particulate matter once it is exposed to water and so making it easier for any cemented matter to lift off of the panel surface. In addition to this the solar panels will be inclined between a degree of 30° to 45°. This can be made possible by having a mechanical arm that can be adjusted between these two degrees at its axis.
We plan on working with OfGen, one of the leading solar companies in East Africa to test the prototypes of the solar panels with the suggestions made above. We will have a control solar PV panel and three other panels to test which combination of solutions would work best for the market.

4. Conclusion

The work presented in this report is part of the activities under development for the selection and characterization of the photovoltaic technology more suitable in solar cooking. Monocrystalline solar panels are the most accessible and cost-effective device to power the electrical cookers. The power of the panels is also an important feature to design the cooking device. Panels with a power range of 220-450 W will be employed in this project.

The selected PV panel is characterized by the ease of cleaning, moderate cost, simplicity in the installation, high performance and easily accessible in the locations of piloting. In addition to the PV panels, electrical components are also needed to assemble a solar cooker: charger controller and DC booster. In addition to these essential components, two optional elements can also be incorporated to the device: inverters and batteries. We have described with details the main characteristics of these components to fabricate a reliable PV solar cooker.

In general priority should be given to polycrystalline solar cells technology, due to costs advantages.Where space for installation of solar panels is limited, priority should be given to monocrystalline technology, considering its higher efficiency. Where air temperature is very high (arid and semi-arid areas), priority should be given to monocrystalline solar cells technology, due to less heat tolerance of polycrystalline modules.

Also, the performance of solar panels is strongly dependent on somehow neglected parameters as soiling. We have carried out a profound analysis to propose novel strategies to reduce soiling, as for example module tilt angle, covering with super hydrophobic or hydrophilic films, use of electro dynamic screen and site selection of the panels. Among the approaches to remove soiling from the panels, we have proposed the water-dependent cleaning, the electrostatic cleaning and the mechanised cleaning.

The importance of the soiling issue in the PV solar panels installed in the Sub-Sahara Africa region is a key factor to maintain the initial high efficiency of the silicon panels. It is important to note that implementation of PV technology in solar cooking is an unknown field with lots of work to be developed. Up to now, there are a few reports published in research journals mentioning the chance to couple solar electricity to power small hot plates. The design and development of real prototypes that can meet the requirements of the rural inhabitants of the Sub-Saharan Africa is of great challenge.

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Summary

The work presented in this report is part of the activities under development for the selection and characterization of the photovoltaic technology more suitable in solar cooking. Monocrystalline solar panels are the most accessible and cost-effective device to power the electrical cookers. The power of the panels is also an important feature to design the cooking device. Panels with a power range of 220-450 W will be employed in this project. The selected PV panel is characterized by the ease of cleaning, moderate cost, simplicity in the installation, high performance and easily accessible in the locations of piloting. In addition to the PV panels, electrical components are also needed to assemble a solar cooker: charger controller and DC booster. In addition to these essential components, two optional elements can also be incorporated to the device: inverters and batteries. We have described with details the main characteristics of these components to fabricate a reliable PV solar cooker. In general priority should be given to polycrystalline solar cells technology, due to costs advantages: Where space for installation of solar panels is limited, priority should be given to monocrystalline technology, considering its higher efficiency; Where air temperature is remarkably high (arid and semi-arid areas), priority should be given to monocrystalline solar cells technology, due to less heat tolerance of polycrystalline modules. Also, the performance of solar panels is strongly dependent on somehow neglected parameters as soiling. We have conducted a profound analysis to propose novel strategies to reduce soiling, as for example module tilt angle, covering with super hydrophobic or hydrophilic films, use of electro dynamic screen and site selection of the panels. Among the approaches to remove soiling from the panels, we have proposed the water-dependent cleaning, the electrostatic cleaning and the mechanised cleaning. The importance of the soiling issue in the PV solar panels installed in the Sub-Sahara Africa region is a key factor to maintain the initial high efficiency of the silicon panels. It is important to note that implementation of PV technology in solar cooking is an unknown field with lots of work to be developed. Up to now, there are a few reports published in research journals mentioning the chance to couple solar electricity to power small hot plates. The design and development of real prototypes that can meet the requirements of the rural inha...

Approval

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