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Development of SolenX: A reliable and cost effective solar aid box for underserved and rural areas in Palestine

Tamer Khatib[a,*], Ammar Shaar[a], Farah Alhamad[a], Heba Dwikat[b], Raya Shunnar[c], Mohammed Othman[b]

[a] Department of Energy Engineering and Environment, An-Najah National University, 97300 Nablus, Palestine
[b] Department of Industrial Engineering, An-Najah National University, 97300 Nablus, Palestine
[c] Alliance Manchester Business School, The University of Manchester, Manchester M13 9PL, UK

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ABSTRACT

An estimated 16% of the world's population do not have access to electricity, and most of them live in rural areas. A reliable energy access for rural communities will help them break out of the cycle of poverty and will empower significant socio-economic benefits. Specifically, the energy sector situation in Palestine suffers from scarcity of traditional energy sources, financial crisis and unstable political conditions. Meanwhile, Palestine has high solar energy potential and an annual average solar radiation of about 5.4 kWh/m^2 day. This article provides a solution by designing a solar home system represented by a small, lightweight, decentralized and autonomous generation with a combination of four different electric appliances to cover several basic needs. The design is assessed by using the product design knowledge as this publication presents an overview of the approach used in structuring and using product design tools leading to shape formulation of system which is called SolenX. The paper also examines a business model that creates a heuristic logic to connect technical potential with the realization of economic value while addressing the total estimated manufacturing cost of $416 per unit. SolenX is powered by a 60 W foldable solar panel with a battery capacity of 0.480 kWh.

1. Introduction

One of the major challenges of the twenty-first century in energy and global development is electricity access [11]. About 1.1 billion people around the world have no access to electricity [15]. Of those, 84% live in rural areas and more than 94% reside in Sub-Saharan Africa and developing Asia [16]. In specific, Palestinian Territories have a large number of remote villages with bad socio-economic conditions where residents have no connection to the electrical grid [22,2]. This lack of electricity services implies laborious work in many domestic tasks to secure basic needs. For example, individuals would put huge efforts on collecting wood to burn for lighting. Meanwhile, candles and kerosene lamps used in these areas provide a low quality indoor combustion-based lighting [21] and would consequently cause severe negative health effects [34]. Indeed, grid expansion is a vital subject and could be a long-term solution. However, the low demand of electricity and being geographically distant make these communities unlikely to be reached by the extension of the grid. Moreover, the high investment cost in grid expansion and the current political situation of energy in Palestine are considered main obstacles for this solution [3].

In general, implementing off-grid PV systems in Palestinian remote areas primarily relies on subsidies and donations from non-governmental organizations (NGO's). However, the existing political situation imposes severe restrictions on foreign funding to such NGO's. Many other obstacles such as the technical difficulties, the high costs and the lack of maintenance and supporting policies prevent the wider expansion of PVs [2]. Alternatively, some of the underserved communities use electricity diesel generators. However, this solution is considered an economic burden since many residents cannot afford the cost of such a technology and its fuel. Moreover, these generators have a negative impact on the environment and a low reliability due to their frequent faults. Thus, an alternative solution for electricity shortage in these communities should give priority to sustainability and should have a minimal negative impact on the environment.

Solar energy based systems are an interesting option in this case since Palestine is well suited for the utilization of solar energy. Many previous research works have been conducted so far to tackle the application of solar energy in developing countries with similar conditions

* Corresponding author.
E-mail addresses: t.khatib@najah.edu (T. Khatib), ammar.shaar@stu.najah.edu (A. Shaar), f.alhamad@stu.najah.edu (F. Alhamad), hiba.dweikat@stu.najah.edu (H. Dwikat), m_othman@najah.edu (M. Othman).

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to Palestine [3]. For instance, solar cooking systems were recommended as they are simple and do not have environmental impacts. However, they provide limited added value, as the cooking process would be very slow. Examples of solar energy based systems that cover cooking needs are presented in Reddy and Rao [29] and Kumar et al. [18]. On the other hand, concentrating solar cookers like parabolic cookers, are faster but potentially dangerous due to the concentrated sunlight and its uncontrolled cooking rate. Details on parabolic cookers are available in Badran et al. [7] and Abu-Malouh et al. [1].

Other types of solar based systems for underserved and rural areas were previously proposed. Wamukonya [33] provides a study on the effectiveness of Solar Home Systems (SHS) in Africa. She claims that if the actual cost of an SHS is reviewed closely and compared to the services it provides, many advantages can be achieved. On the other hand, the features of rural electrification in India and the feasibility of Photovoltaic SHS are assessed by Kamalapur and Udaykumar [17]. Covering the lighting needs is considered as the most important infrastructure for rural areas. Malaviya and Ranade [23] discuss the potential of an SHS for lighting needs. Similarly, a solution in the form of an SHS to cover the needs of cooking and lighting in rural areas is provided in Zubi et al. [37] while techno-economic assessment of an off-grid PV system that provides electricity to cover basic domestic needs is studied in Zubi et al. [35]. Furthermore, detailed comparison between kerosene lamps and an SHS powering LED lamps is presented by Zubi et al. [36].

Based on the aforementioned studies, literature shows that researchers have put huge efforts into studying and proposing different SHS to cover specific needs of underserved communities. However, a SHS that covers a collection of different needs such as lighting, refrigerating, charging and others, has still not been carefully investigated. Under severe economic constraints, a key factor for a successful portable solar box in remote areas is to limit its application to appliances that add a very high value. This act would save the time spent for domestic basic tasks, preserve a healthy living environment, provide suitable conditions to perform educational tasks and finally would take advantage of innovations in energy efficiency and cost reductions. Therefore, this research aims to develop a new product which is a portable SHS that provides five different services to secure multiple basic needs. This product is called SolenX and it is represented by a small, lightweight, decentralized and autonomous generation, and targets providing underserved families in remote areas with electricity to cover their basic needs. The proposed solar aid box comprises three basic appliances which are LED lamps, an Insulin mini refrigerator and an electric mosquito shocker. In addition, the product has two USB ports allowing the recharge of portable electronics like mobile phones. Finally, a battery charger is included to recharge a wide selection of batteries.

This context of new product development entails the implementation of various concepts and tools that will contribute to the complete development of this SHS. A major aspect to address here is the design and development of the system as a product. Product development focuses on a sequence of steps beginning with market opportunity and ending up with delivery of a product [32]. Thus, concepts such as generation and evaluation are identified as the two major activities needed for obtaining an optimal design scheme. Moreover, Bloch [8] claims that when designing a new product, its exterior form is one of the most fundamental characteristics that must be taken into consideration. In addition, there are other important characteristics that receive the largest amount of perceived information conveyed by the external characteristic elements of product such as shape, colour, size and material texture (Desmet and Schifferstein 2008). Other concepts like the Quality Function Deployment (QFD) prove to be appropriate to use, as it is an engineering tool that would translate the needs of underserved families into technical specifications with respect to potential competitive solutions. Akao and Mazur [4] state that QFD was created under the umbrella of Total Quality Management (TQM) to improve the quality of products or services through specific methods. Furthermore, a business model of such new products represents a form of entrepreneurial opportunity creation. Other research suggests that business models represent the source of new value creation and potential competitive advantage. A successful business model requires the integration of suppliers, partners, resources, customers and other actors into cooperative networks that develop with market conditions.

In sum, various concepts and tools need to be implemented to produce a successful solar aid box. These notions will be discussed in details in the rest of this research. The remainder of this paper is structured as follows. Section 2 provides information on system's electrical appliance, consumption and sizing. Section 3 discusses the design and development aspects of SolenX and demonstrates the use of different engineering tools. Section 4 studies the subject of material selection and the process that underlies it. Section 5 displays the business model for SolenX using the business model canvas tool. Section 6 details the costs related to the manufacturing of SolenX and categorizes them into three categories. Section 7 sums up the results of this research and finally, Section 8 provides the conclusion and suggests important areas for future research.

2. System's electric appliances, consumption and sizing

In this paper, the focus is given for designing a portable SHS that provides electricity for Palestinian families in rural areas to cover their basic needs. In this section, more details are provided on the four electric appliances which will be offered by the system. These electrical appliances are led lamps (two units), insulin refrigerator, USB ports, a mosquito shocker as well as a battery charger.

LED lamps have a substantial efficiency advantage and are characterized by their high luminous efficacy especially at lower power levels. This is demonstrated clearly when comparing the luminous efficacy range of LED lamps which is 70–100 lm per watt (lm/W) with both fluorescent and incandescent ranges which are 50–70 lm/W and 11–16 lm/W respectively. LEDs have the ENERGY STAR label by meeting the energy efficiency requirements set forth in ENERGY STAR product specifications. The lab record for LED lamps currently is 303 lm/W. In terms of colour rendering index (CRI), LED lamps are superior to fluorescent, where the value of CRI in LED ranges from 65 to 95. The benefits of LEDs are obvious when it is used in an off-grid system. They last longer than any light source commercially available on the market. According to its lifespan, the typical values range from 20,000 to 25,000 h of operation. In other words, on an average use of 5 h per day, the lifetime will be over 10 years. LEDs have no movable parts or filaments that can be damaged, and the degradation rate of them is slow due to the relatively slow operating temperature. There is still durability improvement potential of LED lamps that is expected to extend the lifespan even more in the near future. Although that the cost of purchasing a LED lamp on a per lumens basis is relatively higher than other lamps, it consumes less energy than the incandescent by at least 73 per cent, which as a result saves operating expenses and reduces maintenance costs. Thus, it can be considered the cheapest option in terms of total cost. In recent years, the cost of LED lamps has been reduced rapidly, reaching a typical consumer of around 1 euro per lumen. Prices are expected to decline to around €0.5 per 100 lm within the next few years. LED luminaires are inherently DC electrical loads powered mostly by 12 V or 24 V. This results in significant power saving in terms of conversion losses as they will be powered by a battery in our case.

On the other hand, a mini Insulin refrigerator is used mainly to maintain the Insulin under suitable thermal conditions and keep it valid for use when needed. The added value of the insulin refrigerator to the system is huge taking into consideration that diabetes is peculiarly common in Palestine, and it is well known that Insulin is a constant companion for patients with diabetes. In remote areas, where no electricity is available, they walk long distances to keep and use their