

Reviewing the feasibility for a renewable society powered by photovoltaic boards

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Abstract. This paper investigates the feasibility of pursuing a future for renewable energy with photovoltaic boards by reviewing economic and environmental data. Initially, in order to meet society's always-increasing need for electricity, the paper envisions a future with microgrids and looks into the possibility of including photovoltaic boards or lithium-ion batteries. First, the long-term prognosis, subsidies, and initial costs are all taken into account in the economic aspect. In this research, data from NREL and FORBES are reviewed. Secondly, through the analysis of environmental data – taken from various research papers -- the production and recycling methods are compared. By combining the two analyses, the conclusion ultimately deems the future for a world of solar energy as practical. Lastly, improvements and suggestions are provided to augment the feasibility of the future that is more dependent upon solar panels which include the enhancement of daily practices, installation, and economic and environmental suggestions for the governments.

Keywords: Photovoltaic boards, lithium-ion batteries, energy, sustainability, micro-grids.

1. Introduction

With the advancement of our technology, an increasing number of the world's population relies on electricity. Despite the seemingly easy ways to turn on the switch or to plug in a device to charge, there are a lot of implications behind electricity storage including environmental and economical complications. The purpose of this review study is to examine the question of how effective solar cells are as an energy storage technology. Batteries are currently the primary form of storage. They are reasonably well-developed and convenient, but they also provide certain environmental risks. The major theme of this review paper will be divided into three smaller topics: economic analysis, environmental analysis, and finally, possible ways to improve the effectiveness of the current approaches.

2. Energy Consumption Trends

Energy consumption includes various sectors, including commercial, industrial, residential, and more. In this review paper, residential energy consumption trends will be the focus of the analysis. Future energy needs will rise due to the constant development of new technology and the transition to a technological lifestyle. Over the previous 20 years, the residential area's energy consumption had doubled. The globe needs a safe and environmentally responsible method to store energy for houses because of the surge in the world's population and demand for energy.

To enhance stability, microgrids can be incorporated into homes. Microgrids are self-sufficient systems that run in specific geographical regions, including but not limited to homes, college campuses and business centres. Every microgrid has one or more energy sources (solar, battery, wind, hydro, etc.) that regulate its power, and some cutting-edge microgrids also feature an energy storage system. Every microgrid is autonomous and limited to its immediate surroundings. For example, the microgrid installed for one college campus can only serve that certain college campus [1].

Due to their independence from other micro-grid systems, the residential areas will maintain the usual power despite exterior circumstances from the grid, for example, blackouts. Having microgrids is distinct from having just solar panels. Although solar energy storage can reduce the financial need for electricity from power plants, these homes will still experience a blackout if the neighbourhood experiences one. Microgrid energy storage can be accomplished in two different ways: one using solar panels and the other using batteries. Every data comparison will examine current conditions as well as prospective future developments for these two approaches.

3. Energy Consumption Trends

3.1. Economic trend of batteries (2022 to 2050)

The National Renewable Energy Laboratory (NREL) conducted a study on the future trend for lithium-ion batteries. The economic predictions of batteries are projected from 4-hour lithium-ion storage systems. The economic values are expressed in units \$/kWh and \$ are converted into 2022 USD with the respective consumer price index (the price change that is experienced by a country's citizens). To convert from \$/kWh to \$/kW, one needs to multiply the amount by the duration of the operation, in this case 4 hours. The following equation was used to provide the most accurate cost estimation.

$$\text{Total Cost (\$/kWh)} = \text{Energy Cost (\$/kWh)} + \text{Power Cost (\$/kW)} / \text{Duration (hr)}$$

In the graph depicted in the paper, regardless of the high, low, or median cost, all three lines show a decreasing trend. The price decrease allows for easier access for both consumers and producers. One cause of this decreasing trend could be economies of scale.

The lowest, median, and maximum points in 2023, 2024, 2025, and 2030 are the definitions of the low, mid, and high trend lines. Nevertheless, the high estimate ends after 2030. Hence, from 2030 to 2050, it is assumed that by 2050, the projection of a 5.8% decrease will continue. The reduction trend for normalized storage cost by year is listed in the table below.

Table 1. The reduction trend for normalized storage cost by year.

year	low	mid	high
2022	100%	100%	100%
2023	72%	96%	104%
2024	68%	92%	104%
2025	64%	81%	103%
2026	62%	78%	99%
2027	59%	75%	95%
2028	56%	73%	91%
2029	54%	70%	88%
2030	51%	68%	84%
2031	50%	67%	83%
2032	49%	66%	83%
2033	48%	65%	82%

Table 1. (continued)

2034	47%	63%	81%
2035	46%	62%	81%
2036	45%	61%	80%
2037	45%	60%	80%
2038	44%	59%	79%
2039	43%	58%	79%
2040	42%	57%	78%
2041	41%	56%	77%
2042	40%	55%	77%
2043	39%	54%	76%
2044	38%	53%	76%
2045	37%	52%	75%
2046	37%	51%	75%
2047	36%	50%	74%
2048	35%	49%	73%
2049	34%	48%	73%
2050	33%	47%	72%

All the predicted trends are strictly decreasing in the table above. Reaching 67% reduction for low trends, 53% reduction for mid trends and 28% reduction for high trends. Hence, it is safe to conclude the decreasing trend will likely continue in the years after 2050 [2].

In addition to the declining prices, over the next few years, government subsidies will also decline. For battery cells, the IRA now provides a 35 USD per kWh subsidy, and for battery modules, an additional 10 USD per kWh. The direct production subsidy received will drop by 25% by 2030, 50% by 2031, and 75% by 2032, according to the IRA. Alas, it will phase out and the companies will no longer receive subsidies. There are indirect production subsidies as well like tax breaks, however, these are harder to determine with the everchanging laws in the country.

3.2. Economic predictions of solar panels (2011 to 2050)

Like battery production costs, the production cost for solar panels is modelled to be decreasing as well. In a study conducted in 2011, it found that by 2020, the price of producing a solar panel module will decrease by 67%. The decreasing trend is likely to continue in the future as technology advances.

To install a solar panel costs around \$12,700 per household in the US. At \$1 to \$1.50 per watt, monocrystalline is the most widely used option. A single-watt solar panel costs, thus, \$400 to \$600. The energy produced can offset the ostensibly high cost. The least efficient polycrystalline panels are cheaper than monocrystalline at \$0.75 per watt, making a 400-watt panel at \$300. On average across all United States (with data generated from all 52 states by Forbes), each household earns around \$1700 annually from solar panels alone [3].

In the worst-case scenario, the cost doesn't change over the course of an average solar panel's 25-year lifespan. Every year, the majority of solar panels lose roughly 0.5% of their efficiency. Therefore, the lowest anticipated lifetime for a typical solar panel is 25 years. Due to economies of scale, as more households adapt to using solar panels (when demand increases), the average cost of production decreases, hence can potentially decrease the market price.

4. Environmental Analysis

4.1. Carbon footprint in the production of batteries

A variety of active techniques, primarily made of metal oxides, are used as cathodes in lithium-ion batteries. Lithium cobalt oxide (LiCoO₂), lithium manganese oxide (LiMn₂O₄), lithium iron phosphate (LiFePO₄ or LFP), and lithium nickel manganese cobalt oxide (LiNiMnCoO₂ or NMC) are a few examples of these metal oxides. In other words, companies need to mine for lithium, cobalt, aluminium, manganese, and nickel in order to produce lithium-ion batteries. One popular technique in the industry is open pit mining, also known as opencast mining. Miners would extract minerals from an open pit (borrow) in the ground.

When a pit is opened, it can stretch for tens of kilometres. Before opening the pit, certain environmental characteristics must be modified to ensure the safety of the project. One of which includes depleting water from its surrounding areas to avoid flooding. The extra water would be poured into gutters, reservoirs, and streams close by, raising the water levels in the neighbourhood. This would filter atmospheric precipitation and accelerate the flow of water from open reservoirs and gutters into the open mines. Additionally, there would be a redistribution of groundwater's hydrostatic and hydrodynamic pressure.

Aside from the environmental impacts of water, air pollution is also a major consequence. When the pit is opened, the dirt particles get blasted out, impacting the surrounding habitats, and living conditions. The total volume of dust clouds can reach approximately 75km³-100km³ per year and the amount of dust transported is approximated to be 1.0-2.5 million tons.

Moreover, the lithosphere – the solid, outer part of Earth -- is also disturbed. Explosives are used sometimes to open a range of land for the sake of efficiency. As a result, the region's geographic features and geomorphology are lost and, for the most part, cannot be recovered. After being exposed by excavation, the exposed rocks are deposited and severely weathered. Surface flushing, endogenous fires, and landslides are other geographical effects.

Another popular method to obtain lithium is through brine extraction. Like open pit mining, numerous ecological and social consequences arise. In fact, in the U.S. around 79% of known lithium deposits lie within 35 miles of Native American reservation. Conducting brine extraction directly poses a threat to their human rights and cultural integrity. Under the environmental spectrum, pollution, water depletion and loss of biodiversity can arise. Brine extraction requires the evaporation of water within a specific geographical region before lithium extraction. The lack of water poses severe consequences to the surrounding regions and habitats.

Lastly, producing lithium-ion batteries results in electronic waste and an abundance of greenhouse gases. The process of mining the materials, manufacturing cells, modules and battery packs requires an abundance of energy, hence emitting tons of CO₂ and methane. The cumulative energy demand (CED) needed to produce a lithium-ion battery is about three times higher than that of a generic battery, according to the Institute for Energy Research (IER). In addition, the battery is extremely hazardous and raises the risk of fire when disposed of in a landfill. Lithium-ion battery fires caused 124 fires in a Pacific Northwest landfill between June 2017 and December 2020 (of which 21 were recorded in 2018 and 47 in 2020) [4-6].

4.2. Carbon Footprint in the Production of Solar Panels

Most solar cells are made up of silicon semiconductors, glass, silver, copper, indium, and tellurium. Solar panels are lithium-free; however, solar batteries contain lithium. Only the carbon footprint of solar panels is taken into account in this instance [7]. In terms of the environment, collecting silicon and glass is safe and abundant in the natural world.

Furthermore, there are three types of solar panels, in order of the highest to the lowest in terms of efficiency and price, monocrystalline, polycrystalline, and thin film. Creating monocrystalline panels produces the highest emissions compared to producing the other two. Additionally, manufacturing thin-film panels yields the most toxic materials that can be detrimental socially and environmentally. Another

key factor to take into consideration is the transportation of solar panels. The top three production countries are China, the US and Europe. As a result, transportation would be deemed necessary in order to use solar panels in other parts of the world, generating undesired greenhouse gases and leaving a carbon imprint.

Aside from the shipment of each component, which is hard to measure depending on the location of the manufacturer, the recycling process for solar panels may pose detrimental effects on the environment. The four primary components of solar panels—aluminium, glass, copper, and even the plastic junction box—are all recyclable. About three-quarters of solar panels are made of glass, which has a thriving recycling business. Even silicon, which is not yet recyclable, can be repurposed by melting. However, the solar panels may also include trace amounts of other elements, such as internal copper and silver, as well as hazardous substances like cadmium and lead. The factories must separate the materials from each other to recycle them independently.

In addition to the complex recycling procedure, solar panels include trace amounts of essential metals such as indium, gallium, antimony, tin, tellurium, and aluminium. Critical metals are those that play a vital role in several energy systems and carry a high risk of causing supply chain disruptions. Therefore, the market values them. Only certain countries have those specific natural resources to mine, for example, China has been providing 85-95% of the world's rare earth elements. These scarce resources are used frequently in the production of technologies. Even around 2015, more than 80% of indium is used, 35% of lithium and 40% of cobalt [8].

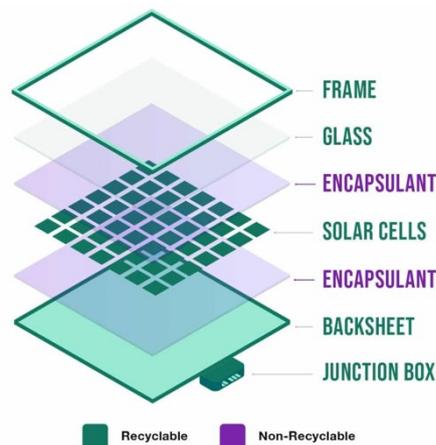


Figure 1. This is a figure showing the layers inside a photovoltaic board and the layers that are recyclable and non-recyclable

The problem lies in the ability to differentiate which materials are hazardous and which ones can be recycled. In Canada, there is a lack of facilities to recycle solar panels due to the inability to identify the hazardous (non-recyclable) levels, therefore causing the small percentage of them being able to be successfully recycled. Even when they can be recycled, multiple tedious steps must be followed.

1. Remove the aluminium frame (fully recyclable)
2. Separate glass (~95% recyclable)
3. Evaporate small plastic components using thermal processing
4. Silicon wafers picked out to be smelted and reused (~85% reusable)

In order to separate glass and plastic from other different materials (mostly metals), each item is roughly the size of sand. After that, the mixture is separated magnetically such that the glass and plastic are separated from the remaining metals. Nonetheless, the business faces numerous difficulties in the process of extracting silicon and separating the metal fragments. The factories cannot conduct large-scale extraction while maintaining high efficacy and efficiency, thereby posing hazardous problems if done unwell [9].

Inadequate facilities can exacerbate both economic and environmental issues. The value of recycled materials is predicted to increase from \$170 million in 2022 to \$2.7 billion by 2030. This presents a challenge for the supply chain that supports the mining and technology industries in their efforts to acquire minerals ethically and with minimal contamination (noise, air, and water). Moreover, it is predicted that by 2050, there will be approximately 7 million tons of photovoltaic waste. This poses strains on both the environmental and economic systems.

5. Improvements Posted for the Future

All in all, solar panels still serve as a better choice than lithium-ion batteries. Their longer lifespan and the high potential for improvements allow for perfection in the future. South-facing roofs produce the highest quantity of electricity throughout the day, followed by East and West. The tilt angle of the solar panel should correspond with the latitude of the house location (i.e., Toronto is at 43.65N, hence the solar panels should be tilted around 45 degrees).

Additionally, when a microgrid is integrated, solar cells' stored energy can be sold to the microgrid at a predetermined threshold. In addition to lessening the load on the government, this can enable households to generate extra revenue from energy grids, encouraging private property owners to make investments in renewable energy. The industry right now is still in its early stages of development, hence not incorporated by many countries on a major scale. One of its reasons is due to the lack of funding the government currently allocates to this industry. The spillover benefits this project brings forth may incentivize governments and other financial institutions to fund the development of this system [10]. Furthermore, subsidies from the government and advertisements can also motivate households to install solar panels. The positive consumption externality because of the government policies will allow the society to function more efficiently, in this case with the promotion of renewable energy.

There is still much to be done to advance the recycling movement, which has only really gained momentum in the last ten or so years. The three top producers of solar panels, China, Japan, and the United States, do not currently have a plan in place for what to do with solar panels that have reached the end of their useful lives. Manufacturers are now only required by law in Europe to gather and dispose of solar waste. Potential can be realized by offering greater advantages to employees in this industry, lowering taxes, providing healthcare benefits, etc. Furthermore, to augment the recycling process, tax cuts or direct subsidies can be given to education and research to enhance technology in the recycling market.

6. Conclusion

Photovoltaic boards hold high potential for the future. With the enhancement of technology daily and the government subsidies provided in this field, the future of renewable energy can be depended upon by photovoltaic boards. Last but not least, solar boards enable individual homeowners to self-produce energy and provide them with the option to sell the excess energy back into the grid. Generally, photovoltaic boards offer a higher probability of being recycled and reused, and the mining process is also safer than Li-ion batteries. A better future in this subject is made possible by the flexibility of these approaches. Due to the long lifespan of photovoltaic boards, improving recycling methods is not too late and once perfected can increase the potential in this industry by miles.

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