Cradle-to-cradle Design Grading Rubric
ENSC 406 – Spring 2016 Sustainability Project

Attach this grading rubric to the front of your paper.

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Introduction/ Motivation	Brief introduction to the product your group selected and why you chose it. (You do not have to describe what C2C is).	**/5**
Product Analysis	Product is analyzed using the fractal triangle to determine how the current product design meets or fails cradle-to-cradle design	
	Economy	**/5**
	Equity	**/5**
	Environment	**/5**
Recommendations for Cradle to Cradle design	Recommendations addressing the deficiencies found in the product analysis are given such that the product approaches cradle-to-cradle design.	**/10**
Format & Language	Proper headings, figures, white space, etc. Clear concise language using proper language and spelling. Document is 8 to 10 pages (not including prefatory pages). Group and topic deadline was submitted on time.	**/5**
Referencing	Proper referencing of ideas/facts using an appropriate referencing convention (i.e., IEEE, APA, or equivalent).	**/5**
TOTAL		**/40**

Comments:

Solar Panel Sustainability
ENSC 406 – Spring 2016

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Introduction

Humans have utilized various energy sources in the world to drive technological advances and maintain the infrastructure of modern society. Sources such as fossil fuels and natural gas have been used to great effect to shape today's countries. However, concerns over the diminishing supply and increasing demand of natural resources have created the concept of energy crises [1]. Various causes of energy crises include an increasing world population and reliance on fossil fuels [2]. Furthermore, concerns about the amount of carbon dioxide in the atmosphere have led to studies performed by the IEA (International Energy Agency) and US NRC (National Research Council) to provide definitive proof of the effects of current energy consumption trends (e.g. higher average global temperatures) [2]. As such, efforts have been made towards finding alternative energy sources to fossil fuels, with an emphasis on sustainable and renewable sources. One source in particular is the sun, which has prompted numerous solar power technologies to be looked into further. Solar panels use photovoltaic (PV) cells (made out of semiconducting materials that absorb photons) to convert sunlight into electricity, and have been in development since the 1950's [3]. One major advantage of utilizing solar panels is that there is significantly less harm done to the environment during the panel's lifetime (compared to fossil fuels), and is essentially "free" electricity. Although the life span of a panel is around 20-25 years [4], producers should keep the cradle-to-cradle (C2C) philosophy in mind to maximize the "cleanliness" of solar power and affect the environment as little as possible. A modern solar panel is analyzed below to see if it meets C2C design standards. Additionally, recommendations have been made to better reflect the C2C philosophies.

Product analysis

The fractal triangle (shown below in Figure 1) will be applied when analyzing the solar panel for C2C design standards. The basic idea of the fractal triangle is that "it shows how ecology, economy and equity anchor a spectrum of value, and how, at any level of scrutiny, each design decision has an impact on all three" [5].

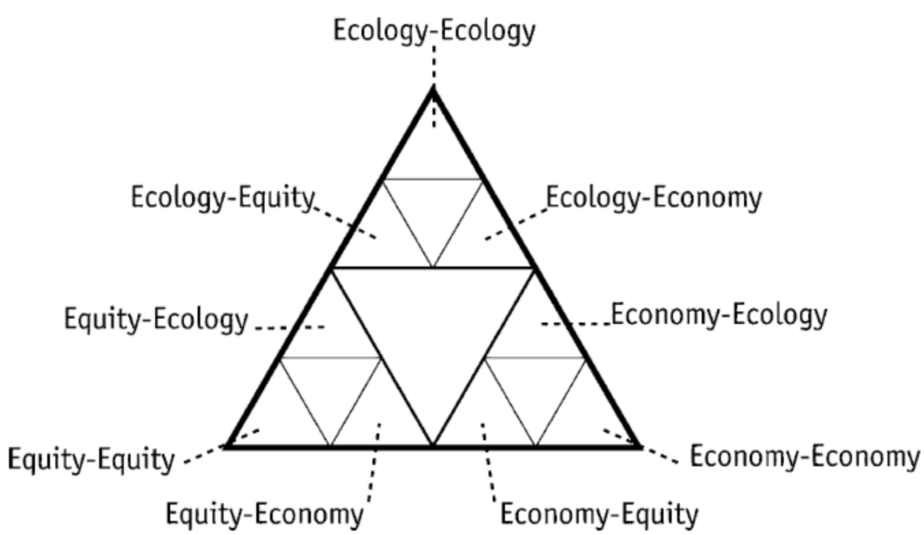

Figure 1: C2C Fractal Triangle [5]

a) Economy

Currently, one disadvantage of solar power is the relatively high cost of producing energy (compared to fossil fuels) [6]. However, as governments are beginning to encourage the use of alternative energy sources, the cost per watt has continued to decrease while the total energy output from solar panels has increased over the past 15 years [6]. The incentives to using PV technology has clearly made an impact on the world's largest economies as China, Japan, and USA implemented the most PV systems in 2014 [7]. In the US, residential and commercial users of PV systems are qualified to "claim a credit of 30% of qualified expenditures for a system that serves a dwelling unit located in the United States that is owned and used as a residence by the taxpayer" [8]. If there are similar motivations in place from various governments, along with increased competition among solar panel manufacturers, the profitability of using solar panels should increase in the coming years. However, in 2015, PV systems still cost more per megawatt-hour than natural gas and coal plants due to expenses from installation and servicing [9].

With that said, solar panels are not currently meeting the economy-economy requirement as there are more profitable alternatives to energy production. According to [10], China has "benefited from government subsidies that have enabled them to sell solar panels below the cost of production". Solar panels would start meeting the economy requirement provided that low cost panels were being produced and installed among most 1st/2nd world countries. However, the profitability of solar power technology would also depend on the costs of other energy sources (namely natural gas and fossil fuels). The viability of solar power technology obviously depends on how much sunlight an area receives throughout the year. Solar panels are considered to be an effective way to creating jobs in "sunbelt" areas, such as Africa and India. Countries like Saudi Arabia have already put in requests for proposals on PV systems while corporations across the US and Europe have started implementing solar panels to move away from utility companies [11].

b) Equity

Solar power impacts low-income homeowners from the sheer amount of jobs that the solar industry creates. Even if they do not usually have solar power systems, users' lives are still improved because of the jobs that are available to them in the solar industry [12]. According to [13], middle-income homeowners benefit the most from solar panel technology as most of the solar power systems are being bought by middle-class neighborhoods. These homeowners can then save money if they use the electricity created by their solar panels or by selling their generated electricity back to the grid. The process is shown below in Figure 2. Note that the grid is not just one tower (as shown in Figure 2), but an interconnected network that delivers electricity from the power plant to the consumers.

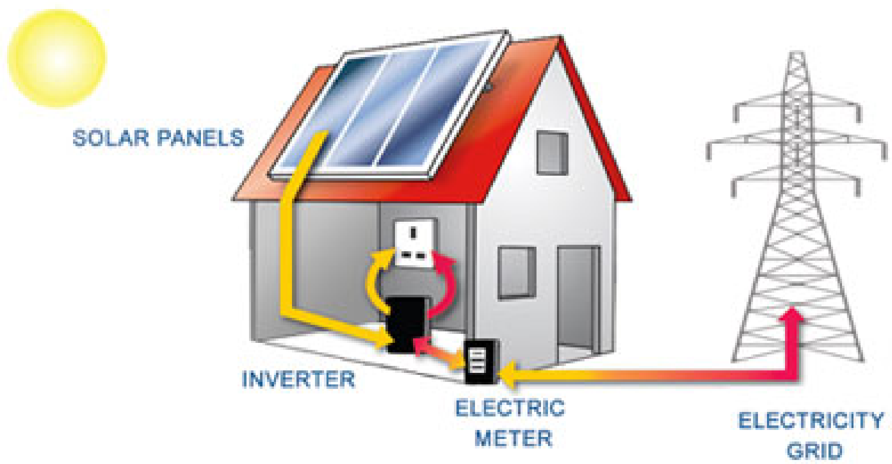

Figure 2: Relationship between homeowner with PV cells and grid [14]

Homeowners can benefit from using solar panels because in many countries (such as Canada, France, or Germany), policies that allow the selling of electricity from solar power are in place. The “feed-in tariff” policy allows renewable electricity (energy from the sun, wind, water, or geothermal) to be sold to the grid. Another policy called “net metering” allows for a similar transaction. Therefore, homeowners that utilize solar panels can make money by sending the generated electricity back to the grid [15].

Larger solar companies have solar panel farms that generate vast amounts of energy for the grid. Other solar companies sell/install panels to customers, or lease their solar installations to consumer’s land. Thus, solar companies benefit from the payment of the customers. Next, the health of employees and customers are enhanced by the use of solar panels. Using solar panels reduces the amount of harmful by-products of fossil fuels. Reducing the output of fossil fuel means reducing the output of unwanted pollutants into the atmosphere. Solar panels create electricity without the waste or emissions that fossil fuels create [16]. Therefore, the health of the employees or customers would be better because of the usage of solar panels.

The solar panels that are placed on rooftops or on buildings do not affect any ecosystems. Solar power farms may be subject to leaky transformers or noisy inverters. However the leaks are preventable by having trained personnel monitor the transformer’s oil temperature, pressure, and level [17]. The noise issues may not be a problem as these farms are usually placed in isolated areas.

Solar panels improve the quality of life of everyone in a community that has them. Homeowners and solar power businesses have their quality of lives improve directly by the use of solar panels, while the environment benefits indirectly because of the reduced use of fossil fuels. Therefore, the quality of life of all solar panel stakeholders are improved and solar panels meet the equity requirement of the Triple Top Line.

c) Ecology

The effects on ecology are not as harmful compared to fossil fuels. For example, coal strip mining damages the land such that the recovery would take 50-100+ years because the soil takes decades to recover. On the other hand, the production of solar power farms requires less soil and hence, the land will recover in a shorter time [18]. Figure 3 below shows a typical solar power farm.

Figure 3: Solar power farm [18]

Large scale solar power farms are a new technology and as such, the long term ecological effects are poorly understood. Figure 3 above shows that wildlife would be affected because the land would be occupied by the solar power plants instead. Therefore, solar power businesses that create such farms are not obeying nature's laws. They would significantly change the habitat of the land they are occupying. Small animal migrations are affected by the huge tract of land enclosed by fences and the vegetation would change from herbicide use and frequent mowing [18].

Overall, solar panels do not meet the ecology requirement of the Triple Top Line. The large scale solar power farms disrupt the ecology and damages the lands they occupy. They damage the land in a less exaggerated way relative to traditional power generation.

Current Recycling Methods

Figure 4 below shows the components of a PV cell made out of silicon.

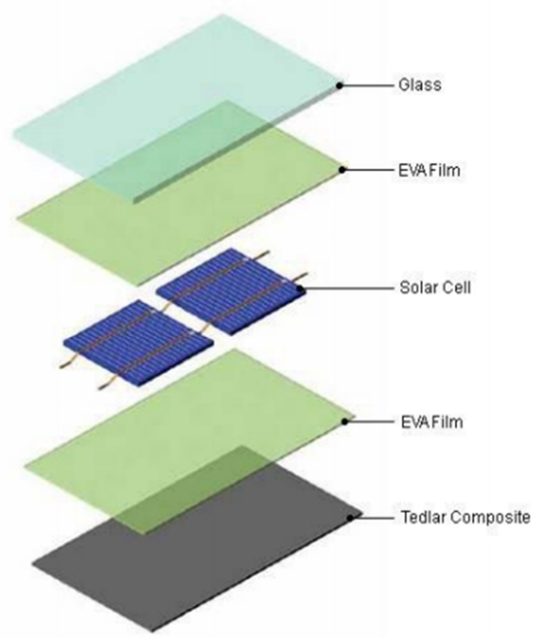

Figure 4: Silicon solar cell components [19]

Silicon solar modules, which are the most common variety, can generally be broken into four major components: a glass or polymer film front cover; encapsulate which adheres the front and back covers to the cell itself (typically comprised of ethylene-vinyl acetate (EVA)); the solar cell, made of either monocrystalline or polycrystalline silicon technology; and a poly-vinyl fluoride back cover, also known as tedlar [19]. These modules are then usually housed in an aluminum frame [20]. Due to these materials, the end-of-life stage of solar modules offers many potential risks if they are not fully recycled. The most serious of these risks is the leaching of lead from solders into soil and groundwater in landfills, but others also include: leaching of cadmium (a known carcinogen that presents several other serious health risks if ingested); significant loss of precious materials such as glass and aluminum; and depletion of rare metals such as indium and gallium (among others depending on the technology used) [20].

Luckily, recycling of most solar modules is effective at significantly reducing these risks and is not dissimilar to already existing processes for recycling many other electronic devices. First Solar, for example, has a process in place for recycling their CdTe (cadmium tellurium) thin-film solar modules. The company manages the logistics of collecting the modules at the end of the panel's lifespan and transporting them to recycling centres. The modules are shredded and then hammered into tiny pieces (< 5mm). Removing the semiconductor film is achieved in 4-6 hours within a slow-rating leach drum using weak sulphuric acid and hydrogen peroxide to etch the film from the glass. Following a few other processes, the glass is eventually recovered while the rinse water is filtered for metal compounds, both of which are then recycled for use in future solar modules. First Solar reports a success rate of 90% for glass and 95% for the semiconductor materials [21].

Silicone crystalline solar modules can be similarly recycled. In 2013, SolarWind launched a pilot program through which usable materials were recovered from old solar modules. After the plastic components are removed, the solar cells, glass, and metal components are manually sorted for recycling. The company typically retains the silicon solar cells for re-etching and reuse while the other components are sent to corresponding recycling centers for general recycling. This process typically recovers more than 90% of the glass and 95% of the semiconductor metals (by weight) from the original modules – all of which can be reused in producing new modules [21]. The thermal processes used for stripping away plastic components does no harm to the silicon solar cells themselves which, depending on level of damage sustained prior to recycling, can be reused as is. Otherwise, the cells can be recycled into raw silicon material [21].

However, some argue that while solar cell recycling is economically viable for thin film solar modules (which use scarce elements, such as CIS (copper indium selenide), CIGS (copper indium gallium selenide), or CdTe), the abundance of silicon makes recycling not as economically appealing for manufacturers of the more common silicon varieties [21]. This falls in the economy-economy section of the fractal triangle. While silicon remains cheaper to purchase rather than to obtain through recycling of old modules, companies which manufacture silicon modules will have no reason to implement recycling programs. More broadly, the entire prospect of recycling suffers from a lack of available centres and limited quantities of solar panels to make recycling of any solar module varieties economically appealing to companies or investors [22]. As McDonough explains, the economy-economy sector is the first to be considered in the fractal triangle. If it cannot be satisfied by a process, the product should not be implemented [5]. So, while silicon modules face much greater obstacles to widespread recycling initiatives, the more appealing varieties may have difficulties justifying the implementation of recycling programs to their shareholders and investors. However, current small-scale and pilot programs show great promise, and future adoption of similar programs will inevitably become more appealing as materials become increasingly scarce and processes are perfected and made cheaper.

Recommendations

Generally, manufacturers should try to make solar panels as cheap as possible so that even lower-income households could afford them. As a result, solar panels would attract more consumers to utilize panels on their rooftops. If that were possible, then the amount of jobs created to assemble, create, and maintain the panels would also satisfy the lower-income households. At the same time, consumers get to enjoy their "free" electricity generated by their own solar panels and can further improve their livelihood by saving money on electricity bills.

Improvements to the productivity of solar panels is another way to improve the economy criteria. A higher megawatt-hour rating would result in more affordable power and the newly generated power can be applied to maintaining society. However, depending on the method used to improve the productivity of solar panels, the improvement in economy depends on a number of factors and is not currently well known. For example, improvements by innovating the materials used to manufacture the panels, can lead to changes in the initial investment cost, and the maintenance costs over time - which as we recommended, must be considered as well.

However, economically viable solar panels can be achieved by using different materials and as a result, cheap solar panels would also save the environment as the usage of fossil fuels would decrease. The air and water pollutions would lessen because of this. It would also mean that the ecology requirement would be achieved because there would be no need to create huge solar power farms when every single house or apartment has them.

More productive solar panels can also improve the environment. By requiring less space to produce the same amount of power, there will be more available space for farm activity. Solar panels can find purpose in previously unusable spaces. The areas where solar panels are placed will be less disruptive to the activity that takes place around it. To summarize our recommendations, we should find alternative ways to make the current solar panels as cheap as possible, and improve its productivity. Doing so will help improve the equity, economy, and ecology benefits from using solar panels.

Conclusion

Energy consumption trends of the past 20-30 years have caused a shift in focus towards renewable energy sources. The development and application of solar panels has ramped up as the cost per watt continues to decrease while total energy produced globally continues to increase. Using the fractal triangle to analyze the current application of solar panels, none of the equity, economy, or ecology requirements is currently being met. Solar panels are still too costly (in comparison to fossil fuels) due to installation and maintenance fees. Furthermore, solar panel farms require vast amounts of land, which can have various consequences (depending on what the land could have been used for). Currently, solar panel recycling procedures have been developed but it is hard to determine if they will be heavily implemented as the cheap cost of silicon decreases the motivation to recycle solar panels. The recommendations made to the modern solar panel revolves around reducing cost such that lower income households are able to afford them. Furthermore, as PV technology advances, solar panels should in turn become more efficient.

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