Technical Review of Constraints and Solutions of Low-Carbon Energy Sources

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Abstract

Renewable energy sources have received increasing attention in recent years, as the urgent need to decarbonize the global economy has become ever-clear with rising extreme weather conditions alongside dramatically changing lives and livelihoods. The most promising forms of renewable energy are identified, and the economic and social constrains that need to be overcome to replace carbon-based energy systems are examined. I then conduct baseline research of the most prominent forms of renewable energy by analyzing the physical science, scalability, and advantages/disadvantages of these technologies. My analysis shows that solar energy can be one of the most promising technologies because of its ability to be rapidly scaled in many different places, require limited maintenance, and provide jobs/return on investment. Within solar, I examine several specific technologies and conclude that crystalline PV has the most potential for rapid deployment to the TerraWatt scale. I continue by examining the current state of business models to identify what constraints need to be addressed to scale and deploy solar and renewable energy more efficiently. Here, my analysis finds that the far-reaching embedding of carbon in companies' supply chains, lack of regulated carbon pricing, and poor societal habits are some of the main obstacles that must be addressed if renewable energy is to be effectively incorporated into business and social systems. This research suggests actions for stakeholders who must play a role in scaling and innovating the technology effectively, and civilians who must change their lifestyles to create and adapt to a more sustainable system.

1 Introduction

This research aims to analyze the world of renewable energy, investigate which renewable energy source holds lots of potential, and determine what constraints need to be overcome for modern society to primarily shift to these energy sources from the current carbon-based system. Before speaking about the primary

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findings of this research, it is first essential to understand the significance of the question being asked, both by examining the overarching topic of renewable energy and the specific renewable energy sources and systems.

Taking a step back, our planet operates in a delicate state of energetic equilibrium. The incoming energy from the sun is balanced between the outgoing energy from the Earth (reflected by clouds, absorbed by the atmosphere or the surface). Essentially, as sunlight warms the Earth, the Earth, in turn, sheds and reflects excess heat as infrared energy is emitted into space. At a certain temperature, the amount of energy leaving the Earth is exactly the same as the amount of solar energy it receives from the sun, therefore maintaining a stable average temperature and climate, allowing for the development of varying organisms and species [Far15]. This equilibrium, which can take form through the carbon cycle, has been in existence since the rise of the planet, incorporates all elements of the Earth, and involves the movement of carbon through the Earth system pathway as follows:

- The atmosphere;

- The terrestrial biosphere, which includes freshwater systems and non-living organic material (such as carbon in the soil);

- The world's oceans, including dissolved inorganic carbon and living and non-living marine biota;

- The sediments (fossil fuels);

- The Earth's interior, carbon from the mantle, and rocks of the crust are released to the atmosphere by volcanic eruptions/geothermal systems.

This movement of carbon and energy can be calculated by the Earth's energy imbalance scale (EEI). The EEI is the difference between the amount of solar energy absorbed by the Earth and the amount of energy radiated back to space. If the imbalance is positive, more energy is coming in than going out, and we can expect the Earth to warm. Consequently, if the imbalance is negative, then more energy is going out than is being received, and we can expect the Earth to cool [Far15]. This is the single most crucial measure of the status of Earth's climate, and it defines the expectations for future climate change. As has been previously stated, historically, the energy imbalance has been stable at around 0 with a constant dynamic equilibrium between the sun and Earth, with occasional jumps in either direction (ice age, big bang, etc.). However, the status quo relating to energy production and consumption is starting to change.

Ever since the onset of the Industrial Revolution in the mid 18th century, our society's use of energy sources has primarily depended upon burning fossil fuels, the most prominent of which are coal plants and natural gas. As the human population grew, the use of fossil fuels followed suit. Moreover, while the human race has experienced an amazing burst of innovation, growth, and expansion since the dawn of the utilization of these energy sources, the amount of energy these forms emit is unlike any our planet has experienced before, negatively disrupting the equilibrium.

Fossil fuels are formed from the decomposition of millions of years old carbon-based organisms and create carbon-rich deposits extracted and burned for energy. The energy created from this can be mechanized in various ways, such as

products like plastic or steel or electricity to power your home. However, the emission of large and unprecedented amounts of carbon dioxide directly into the atmosphere holds severe consequences. Carbon dioxide – a greenhouse gas – when in the atmosphere absorbs and radiates reflected infrared heat from the Earth's surface and therefore traps the energy from the sun, subsequently warming the average temperature of the planet and dirtying the air we breathe [Far15]. Due to carbon dioxide's long atmospheric lifespan (meaning it can remain in the atmosphere for hundreds, if not thousands of years), these emissions are proving to be the leading cause of rising average temperatures and climate change.

Additionally, society's demand, usage, and production of fossil fuels have exponentially increased over time. The graph below from OurWorldinData shows the global fossil fuel consumption since the 19th century, clearly detailing an exponential increase in all three fossil fuels since the 1950s. Alongside this graph, according to the United States Energy Information Administration, or the EIA, petroleum (34.7 percent), natural gas (33.9 percent), coal (9.9 percent), and nuclear (8.9 percent) were the four most consumed sources of energy in the U.S in 2020 (totally around 80 percent of the country's energy), all of which are nonrenewable. This is not just the U.S. – the majority of countries worldwide hold similar figures regarding their usage of energy sources and fossil fuels.

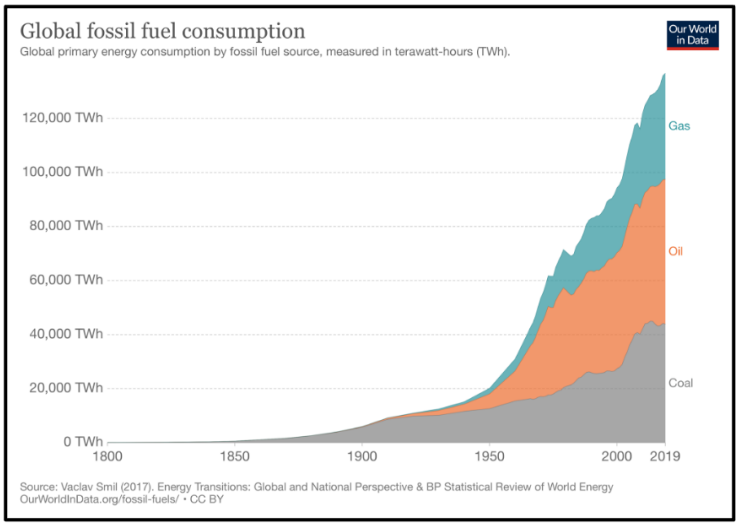

Figure 1: Global Fossil Fuel Consumption Graph [Rit20]

As mentioned earlier, increased production and consumption of fossil fuels have resulted in a global temperature increase. This rise in temperature results in extra energy being trapped on Earth (also known as the greenhouse effect – other greenhouse gases include methane (a prominent form in agriculturex), nitrous oxide (from car exhausts, for example), and industrial gases), has tipped the Earth's energy equilibrium and carbon cycle out of order. Because more carbon is now located in the atmosphere than ever before, the entire cycle is

thrown off, and the Earth's system has to compensate for this added energy by warming [Kra01]. This disequilibrium results in warmer and higher oceans, radical weather changes, unbalanced ecosystems (ocean acidification), changes in the distribution of vector-borne diseases, higher and more frequent maximum temperature days, and, most importantly, a heating planet. If the planet continues increasing temperatures on the current trajectory, it will soon become too hot for humankind's inhabitants, gradually forcing us towards extinction. As mentioned by the recent 2021 IPCC report, this problem is both "unequivocally and indisputably" related to human behaviors and has reached a point the scientists declared "a code red for humanity," with many of the problems we have created already being too late to fix (citing ocean level rises and melting glaciers as examples) [IPC21].

Therefore, to stop this ever-increasing pace of global warming, the solution is clear: we can no longer continue our inefficient utilization and energy formation via the burning of fossil fuels. Of course, reliable energy supply is essential in all economies, but today's energy choices will determine the climate in the coming decades. The IPCC places significant emphasis on limiting the average temperature from warming above 1.5C, whereby scientists believe large portions of the human population would be rendered extremely vulnerable to extreme weather conditions, limited working hours, and fatal environments [IPC21]. Although historically it has been difficult for humans to confront a significant problem until some catastrophe occurs, understanding that if carbon dioxide could be reduced to the level that it was before the Industrial Revolution, the natural system would return to a state of equilibrium, assuming there was no future perturbation to the climate system. The sooner methods are found to reduce greenhouse gas emissions in a sustainable, equitable, and economically and environmentally acceptable manner, the better [Owu16]. A great step towards this goal would be a sustainable mechanism to produce energy without fossil fuels and subsequent emissions of greenhouse gases. This is the world of renewable energy.

Renewable energy comes from natural sources or processes that replenish themselves naturally without being depleted by or depleting the Earth. The sun is the source of all terrestrial energies, with the primary forms of solar energy coming through heat and light, which are both transformed and absorbed by the environment in a multitude of ways. The most common examples of this are the flows of biomass and wind energy, which continue despite their availability depending on time and weather conditions. Renewable technologies are considered clean energy sources, and optimal use of these resources minimizes environmental impacts, produces minimal secondary waste, and are sustainable based on current and future economic and social societal needs [Lun07]. Because of the self-repeating nature of renewable energy sources, these technologies provide an excellent opportunity to mitigate and eliminate pollutants and greenhouse gas emissions and thereby slow global warming by substituting conventional energy sources (fossil fuels). There are countless forms of renewables, but the primary ones investigated briefly in this paper are: hydropower, wind, biomass/bioenergy, geothermal tidal/riverine, and solar, with a particular

emphasis and in-depth analysis on the importance, economics, and technology of solar energy as the body of the research.

1.1 Hydropower Energy

Although its status as a renewable energy source is debated, this paper will consider hydropower as renewable energy for the simple fact that it uses water, and not polluting materials, to generate power. The water cycle is an endless, refilling system, making it a renewable energy source (unlike nuclear energy, which itself is a renewable source but does not use renewable materials power plants, and therefore is not considered to be a renewable energy). Hydropower harnesses water movement from high to low elevation (the primary energy involved is gravity) to turn a generator's turbine blades and generate electricity [Owu16]. The operation of hydropower reservoirs holds various uses, including flood and drought control, irrigation, drinking water, and navigation. Because hydropower relies almost exclusively on gravity and a specified turbine, the energy source discharges practically no particulate matter, can upgrade quickly, increases the stability and reliability of electrical systems, and is capable of storing energy for many hours [Owu16]. Nonetheless, the energy source also has its disadvantages.

Although hydropower can improve a country's socio-economic development, considering the social impact, its creation also displaces many people from their homes (they are sometimes compensated to an extent, but often this is not enough, nor are they given a say in the matter). Also, the construction of hydropower sites like reservoirs is often artificially manufactured and, therefore, can lead to flooding of the natural environment [Owu16]. This is a two-fold disadvantage because not only is the land damaged, but in countries or regions where substantial plants or tree covers are flooded during construction, there may also be the formation of methane gas when plants start rotting in the water. This methane is then either released directly or when that water is processed in turbines [Pan11]. Additionally, hydroelectric structures impact the river body's ecology, mainly by inducing a change into its hydrologic characteristics and disturbing the ecological continuity of sediment transport and fish migration (construction of dams, dikes, weirs). Overall, despite some of these cons, hydroelectricity merits international support for its ability to efficiently and effectively generate power to the grid, provide backup power supply, maintain flood control, irrigation, water supply, and not use fossil fuels during its production.

1.2 Wind Energy

Of the renewable energy technologies applied to electricity generation, wind energy ranks second only to hydroelectric in terms of installed capacity and is experiencing rapid growth worldwide. Wind energy harnesses kinetic energy from moving air and converts it into electricity or mechanical power. The function of these wind turbines is to convert the motion of the wind into rotational energy that can be used to drive a generator, as can be seen by Fig.2 below [Pan11].

Wind turbines capture the power from the wind employing aerodynamically designed blades and converting it into rotating mechanical power via airfoils.

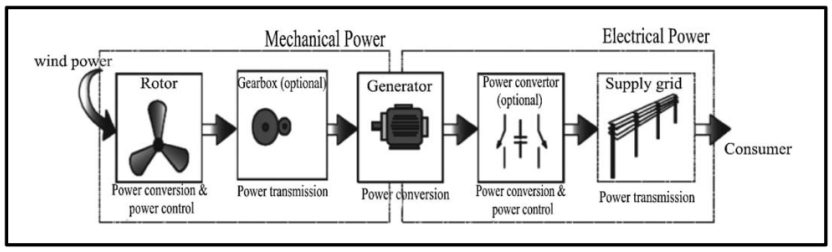

Figure 2: Diagram of Conversion from wind to electrical power in a wind turbine [Pan11].

The primary application of wind energy is to produce electricity from large wind turbines located onshore (land) and offshore (in the sea or freshwater). These technologies are already being manufactured and deployed at large scale around the world, as according to [Off], the entire global wind power fleet, both onshore and offshore, totaled 743 gigawatts (GW) at the end of 2020 (China and the United States lead the way into full use of wind energy), enough to avoid nearly 1.1 billion tons of CO2 emissions globally. Additionally, wind energy is the cheapest form of electricity generation available today (the average American pays 12 cents per kilowatt-hour, while wind costs just 2 cents), and competition from natural gas and solar are poised to push these prices even lower [Far17].

In countries with power shortages, wind power is a viable source of electricity, which can be installed and transmitted very rapidly, even in remote, inaccessible, and hilly areas [Pan11]. Because the power source utilizes natural wind, there are no carbon emissions in its production. The electrical generation from wind never depletes and never increases in price, and could dave several billion barrels of oil and avoid millions, if not billions of tons of carbon and other emissions [Pan11]. The source does have some disadvantages, namely a reliance on wind and disruption of surrounding ecosystems and environments. Wind energy, naturally, relies on wind, which cannot be controlled and is relatively region-specific (some areas of the world have very little wind exposure, unlike gravity and water in hydroelectric sources). This results in wind energy being an intermittent energy source, meaning that unless the energy is effectively stored (the technology for doing so has not been concretely developed thus far), a grid system cannot rely on wind alone. Because grids need to be balanced, cities could face large-scale blackouts if the wind stops blowing during any given period. Also, the turbines used to generate the energy can harm the environment and wildlife of the surrounding area (primarily birds flying around or disrupting ecosystems). However, along with the advantages already given, wind energy provides jobs, enables industry growth, and is cost-effective, making wind energy an extremely viable alternative to fossil fuel consumption.

1.3 Biomass/Bioenergy

Bioenergy is a renewable energy source that is derived from biological sources or organic matter. These sources include agricultural and food waste (manure, compost, etc.), plants, and wood residues (timber). The energy harvested from these sources is collected via burning, bacterial decay/decomposition, and conversion to a gas or liquid (biogas and biodiesel), which is then utilized for various purposes, including transport using biodiesel, electricity generation, cooking, and heating. This form of renewable energy holds some significant advantages, as it helps close the loops from production of energy to utilization by optimal recycling measures [Pan11]. Because fuel is often simply a by-product or residue of the natural bioenergy sources, it emits no greenhouse gases. It is, therefore, highly energy-efficient, and even more significantly, does not create competition between land for food and land for fuel (which wind, solar, and other renewable energy sources do).

Additionally, bioenergy can be produced when needed, stored easily, distributed through existing natural gas infrastructure (basically used in the same application as natural gas), and can be directly used for cooking or transportation [Owu16]. The current global production of biofuels is comparatively low but continuously increasing worldwide as technologies become more advanced. Some disadvantages include the worsening of vegetation and forest degradation and the costs of harvesting and transportation. However, overall bioenergy technology provides an excellent opportunity, if utilized at scale, for mitigation of greenhouse gas emission and reducing global warming via the substitution of fossil fuel-related materials (firewood, chemical fertilizers, etc.).

1.4 Geothermal Energy

Geothermal energy is the heat from the Earth's interior/sub-surface contained within the rocks and fluids beneath the Earth's crust (magma, molten rock, etc.). The heat is mined from wells dug up or drilled into underground reservoirs, where once it is drawn to the surface, fluids of various temperatures can be used to drive turbines to generate electricity, among other energy sources. There are three types of geothermal power plants: dry steam, whereby steam is absorbed from the ground and driven into a turbine; flash, where hot, high-pressure water is cooled; and binary, where hot water is passed through a sequence of liquids to turn into vapor and drive a turbine [Adma]. This energy source is currently being used in around 20 countries worldwide and holds potential in others, particularly in countries such as Iceland, where large amounts of hot springs and volcanoes make it an ideal energy source. According to the British Geological Survey, geothermal energy only produces one-sixth of the CO2 produced by a natural gas plant and is not an intermittent source of energy like wind or solar (there is no reliance on the sun or the wind). There are, however, some drawbacks. Despite lower CO2 emissions, geothermal has been associated with other toxic emissions such as hydrogen sulfide or sulfur dioxide. Geothermal also has initial building costs, the potential for environmental disruption (mini

tremors from power plants), and is very location-specific due to its activity only being truly effective along tectonic boundaries [DF04]. Therefore, despite some positives, its production is often limited in many major countries.

1.5 Tidal/Riverine (Ocean) Energy

Tidal, riverine, or ocean energy is energy generated from the surge of water during high and low tides. Like other renewable energy sources, the rushing water is then inputted into specialized generators to create electricity. The three current types of tidal energy are tidal streams, where turbines are placed in tidal streams, and the following water turns a generator to produce electricity; barrages, which uses a dam or walls to capture and store the potential energy of the flowing water (usually ocean); and tidal lagoons, which work in a similar way to barrages by capturing a volume of water behind an ocean body of water partly enclosed by a barrier (either natural or manufactured), and then releasing it to drive turbines. These forms of ocean-based renewable energy are still in the early stages of development, with the first year of commercial ocean energy services in the United Kingdom and Portugal coming in 2008 [Est12]. Again, potential cons include the environmental impact of ecosystems where turbines are constructed and the scarcity of suitable locations. However, considering the ocean stores enough energy to meet the worldwide power demand efficiently, this form of renewable energy can be of great use in the coming decades.

The rest of this paper focuses on the most prominent form of renewable energy not yet mentioned: solar. Because of its ability and potential to harness the Earth's leading source of energy, solar power, if incorporated and developed efficiently, will be one of the most important renewable energy sources in the coming decades. I will take a more in-depth look at solar power technology and its feasibility. First, I will examine solar technologies in two sections, solar thermal + concentrated solar power (parabolic troughs, fresnel mirrors, power towers, solar dish collectors), and photovoltaics + concentrated PV (e.g., crystalline silicon, thin-film (CdTe, organics, perovskites, CPV using GaAs)). I will then examine the economics, scalability, efficiency, and the overall advantages and disadvantages of solar energy, comparing it to some of the other aforementioned sources. Finally, I will investigate the current state of business and societal models regarding incorporating these technologies (along with renewable energy more generally) effectively and efficiently, researching what current constraints are preventing mass distribution and production of renewable energies. I conclude by proposing possible economic and lifestyle-focused solutions to help us lower carbon emissions and become more sustainable.

2 Primary Research Findings and Discussion

2.1 Solar Energy Technology Analysis

As far as renewable energy sources are concerned, solar energy is by far the most abundant and available in both direct and indirect forms. The concept of solar energy is to harvest light and heat energy from the sun and then generate or utilize it using varying technologies to apply across multiple applications. The sun, the source of solar energy, is the Earth's leading source of inexhaustible free energy, emitting energy at a rate of approximately 4.26 million metric tons per second, and theoretically, solar energy possesses the potential to adequately fulfill the energy demands of the entire world if technologies for harvesting and supplying were readily available [Kab19]. Therefore, global adoption of solar technologies would significantly mitigate climate, energy, and related economic concerns. Solar is a sustainable alternative to generate electricity, process chemicals, or even space heating like other renewable sources. Solar energy has seen rapid development and increased popularity (particularly in the engineering sciences) over the past few decades. It has become a tool to develop the economic status of developing countries and sustain the lives of many underprivileged people [Pan11]. Solar is abundant, accessible, and clean, both in terms of greenhouse gas emissions and noise production, making it one of the most promising and advantageous renewable energy sources. This energy source has a variety of applications, including but not limited to: agriculture, telecommunication, cooking (hot water, drying, steam, dehydration processes, sterilization), chemical reactions, industrial space heating, building industry (to operate heaters, pumps, engines, fan, etc.), textile, or even business-related industries [Mek11].

Currently, there are two ways to harness solar energy: passive or active solar technologies. Passive solar technology is solar energy collection, storage, and distribution in the form of heat directly from the sun (for example, heating a home is a form of passive solar) [Kab19]. Standard solar technologies for passive systems include thermosyphon systems, integrated collector storages, and solar stills (none of which are mentioned in detail in this paper). Active solar energy technologies, on the other hand (more of the primary focus of this paper), use mechanical and electrical equipment to convert the sun's solar energy to electrical power or heat (the water heater system is a typical example) [Kab19]. There are two further major forms of solar energy technology and applications within active solar energy: thermal and photovoltaic solar.

This paper will first demonstrate the strengths of some of these various in-depth solar technologies, comparing them to one another, and then reach a broader comparison between solar and other renewable energy sources at the end once that information is established.

2.2 Solar and Concentrated Solar Thermal Energy and Power

Solar thermal is the conversion of solar irradiation into heat and is considered the most economical alternative of renewable energy systems [Mek11]. This energy is typically harnessed for domestic and or commercial applications, such as drying, heating, cooling, cooking, etc. The significant component of any solar thermal energy system are the solar collectors and concentrators, which gather solar radiation, store it, and then transform it to internal energy that can be used for heating air or water in domestic, commercial, or industrial plants [Pan11]. Specific applications are typically determined by the type of collector, storage, size of the system, and total volume [Mek11]. To increase the efficiency of these systems, solar collectors are applied to heat the air or water as the medium of heat transfer. The solar water heating industry thus constitutes the majority of solar thermal applications in domestic and industrial sectors. Fig.3 above shows the general schematic for solar thermal energy conversion.

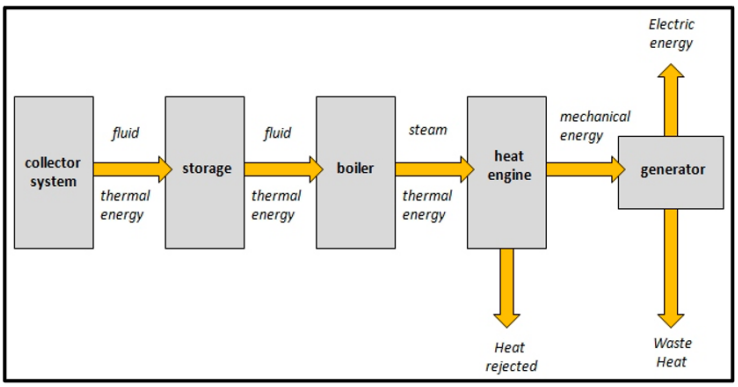

Figure 3: Schematic Diagram of Solar Thermal Energy Conversion [Sta]

There are different types of solar thermal collectors like the one seen on the left of the figure, which can be placed into two broad categories: (i) non-concentrating and (ii) concentrating. In the non-concentrating type, sometimes known as low temperature thermal, the collector area (the area that intercepts the solar radiation) is the same as the absorber area (the area that absorbs the radiation) [Kab19]. The heat produced from the Sun's rays is used directly, which naturally caters to residential and commercial heating and cooling systems applications. This form of solar accounts for large portions of the total solar renewable energy used worldwide. A typical example of such a system is a metal plate that is painted black to maximize the absorption of sunlight – these include flat plate collectors (FPC), designed to be used in low-temperature applications, evacuated tube collectors (ETC), designed for high-temperature industrial uses, and solar thermal air collectors, used for agricultural crop drying. The energy is then collected by cooling the plate with a working fluid (a fluid

or gas that transfers heat or energy).

There are two forms of thermal energy technologies on the concentrated scale: Concentrated Solar Thermal (CST) and Concentrated Solar Power (CSP). These concentrated energy sources concentrate the warmth of the Sun's rays using collectors to heat a transfer fluid (gas, oil, or molten salt, for example) to a high temperature. The fluid heats a network of water, which produces steam and drives a turbine (mechanical energy), thereby generating electricity [Admc]. The technology is naturally best suited to intense sunlight areas (desert regions) because of its demand for high temperatures. CSTs are currently being used to fulfill some of the heating requirements mentioned earlier in industries and homes (heating, cooling, drying, etc.). CSP technologies, on the other hand, are being developed and employed to generate electricity, using high-magnification mirrors or lenses to concentrate solar energy (often to a specific point) by converting it into heat energy to power a steam turbine connected to an electrical power generator [Kab19]. This form of solar energy is distinct for its ability to function as a utility-scale power plant, and it also has the potential to provide baseload power for utilities.

Four models of CSP technologies are currently being utilized on the open market: (i) parabolic troughs, (ii) fresnel mirrors, (iii) power towers, (iv) solar dish collectors [Kab19].

1. Parabolic troughs, which look like curved solar panels (they are straight in one dimension and curved as a parabola in the other two), are lined with a metal mirror that concentrates sunlight onto a receiver tube containing a working liquid [Kab19]. The sunlight is focused along a focal line, which can either be a place where objects are positioned that are intended to be heated or a tube containing fluid, both of which are heated to a high temperature and piped to a heat engine to drive machinery or generate electricity [Duf20]. The solar energy collector mentioned above is the most common form of parabolic trough, and this form of CSP is both the cheapest and most common in the United States.

2. Like parabolic troughs in design, fresnel mirrors use multiple flat, long mirrors to concentrate solar sunlight onto a fixed absorber (commonly a receiver tube) located at a common focal point. This concentrated energy is transferred through the absorber into a thermal fluid that goes through a heat exchanger to power a steam generator [Kab19]. Additionally, the mirrors also do not need to support the receiver, so they are structurally simpler. These systems aim to offer lower overall costs by sharing a receiver between several mirrors (compared with trough and dish concepts) while still using the simple line-focus geometry with one axis for tracking.

3. Solar power towers, also known as "central tower" power plants, are an array of thousands of flat, movable, sun-tracking reflecting mirrors (otherwise known as heliostats) positioned in a field to concentrate solar radiation to a single point (the receiver) [Kab19]. The fluid heated in the receiver produces high-pressure steam, which in turn spins a conventional turbine to generate electricity. The mirrors are computer-controlled and therefore move throughout the day to maintain focus from dawn to dusk. In a steam power tower, water is

pumped to the receiver, where concentrated thermal energy heats it to over 1000 degrees Fahrenheit, and the steam generated is sent to a power block to spin a turbine and generate electricity. In a molten salt power system, cold molten salt is pumped to the receiver, where it is heated, then flowing through a hot storage tank and heat exchanger, which again produces steam that powers the turbine. The power towers can collect and store heat to generate utility-scale electricity 24 hours a day, meaning that cloudy days or nights do not render the energy system ineffective.

4. Finally, solar dish collectors concentrate power by focusing ST energy onto a single point situated above a reflector dish [Kab19]. Like the other forms of concentrated solar, sunlight is concentrated to a single point (collected by the solar dish), collected to a small focal point area in the front of the dish, and concentrated to the heat absorber in the focal point area [Duf20]. From then on, the heat energy is transferred to the turbine and generator to create electricity. The mirrors, which are both cheap, easy to clean, and durable, reflect a high percentage of the sunlight, thus increasing the dish's efficiency compared to other collectors noted above. It is also essential to note that no water is used inside the receiver due to high temperatures at the focal point, and instead, thermal fluid is used to transfer the intense heat generated.

A more visual diagram of the varying concentrated thermal types can be seen below (including a depiction of their technologies).

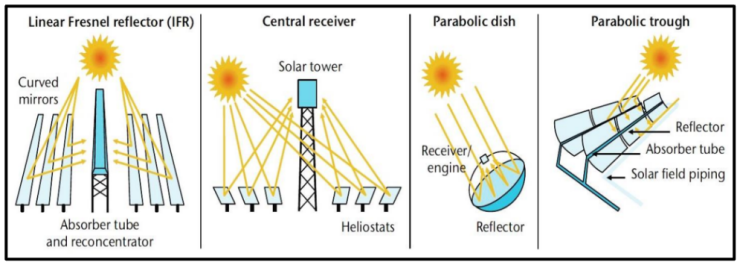

Figure 4: Diagram of Varying Concentrated Thermal Energy Types [Răd19]

In general, the most efficient forms of CSP solar thermal energy are the solar dish and evacuated tube collectors, as they are more durable and require less maintenance than other sources. These solar thermal systems are widely used in industrial processes, such as textiles, food, buildings, or heating [Wan19]. All of these forms of solar thermal energy have both advantages and disadvantages. To generalize it, the significant advantages of solar thermal are that, like any renewable energy, they do not pollute or emit greenhouse gases. Additionally, there is also no fuel cost (thermal does not require any fuel like most other sources of renewable energy), they are reliable and predictable (24/7 power made possible because of the energy stored within the plants (molten salt, for example)), and they use an existing industrial base (not much set up needed). The primary disadvantages of solar thermal energy are the high costs (especially compared to solar PV, which this paper will analyze next), limited scalability

and locations (best place to build them is deserts, elsewhere is relatively ineffective), ecological impacts (noted to heavily impact desert wildlife), and low efficiency [Wan19].

2.3 Solar Photovoltaic Energy

Unlike solar thermal, which produces heat, photovoltaic energy produces electricity. This energy source utilizes direct solar energy conversion via photovoltaic cells, which use the photovoltaic effect (PV effect) [Kab19]. The PV effect depends on interactions between photons, whereby a photon impacts a panel of semiconductors shaped into thin layers (one positive, labeled P, one negative, labeled N), composed primarily of silicon or selenium, exciting and releasing electrons [Pan11]. These conductors, which comprise the core element of solar cells, produce an electric current between the layers when the electrons are released, generating electricity through exposure to light (solar radiation). PV modules generate electricity directly from light without emissions, noise, or vibrations. The most common example of PV technology is solar panels, often placed on roofs or fields to generate and store electricity. Like thermal technology, the efficiency of these solar PV cells depends on the temperature, insolation, spectral characteristics of sunlight (they are not effective during the night or a cloudy day, for example), and so on [Mek11]. Solar PV has become the more desirable option between the two solar technologies in recent years, with improved efficiency, scalability, pricing, meaning it is now best suited to lower GHG emissions and create sustainable, renewable energy. The most common applications of PV technology are for the home, business, agricultural development, and telecommunications.

A diagram of a typical PV system can be seen below.

Currently, these photovoltaic cell technologies, both being deployed at the stand-alone and grid-scale (mentioned later), involve water-based cells (traditional crystalline silicon or gallium arsenide), commercial thin-film cells (cadmium telluride, amorphous silicon, copper indium gallium diselenide), and new thin-film technologies (perovskites) [Kab19]. All of these technologies are progressing with the advent of intense RD efforts.

Starting with water-based cells, the most traditional and commonly used forms are made of crystalline silicon. Silicon solar cells are perhaps the simplest and most widely used for space and terrestrial applications (they represent 95 percent of the modules sold today, according to a 2016 report by the National Renewable Energy Laboratory), primarily because silicon is the second most abundant material on earth. Crystalline silicon cells are made of silicon atoms connected to form a crystal lattice, which provides an organized structure that allows for the efficient conversion of light into electricity [Bla13]. These cells currently provide a combination of high efficiency, low cost, and extended durability (are expected to last over 25 years and still be 80 percent efficient). Currently, silicon solar panels have two varieties, mono-crystalline and polycrystalline (multi-crystalline), serving the same function [Pan11]. Mono-crystalline PV cells are circular and are the most efficient and highest performing solar

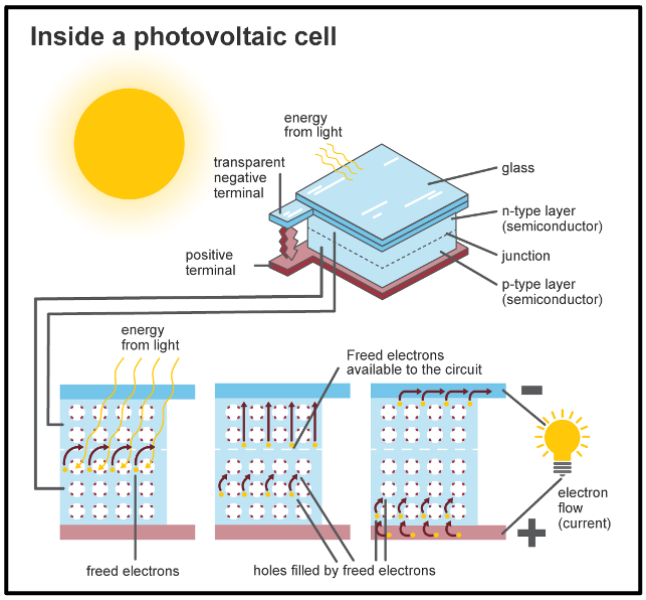

Figure 5: Schematic Diagram of PV Technology System [Admb]

cells currently developed. In these cells, single-crystal silicon is formed into bars and cut into wafers (they are called mono-crystalline to indicate that the silicone used is single-crystal silicon) [Bla13]. Because of their single-crystal nature, the electrons released by the sun's thermal radiation generate a great glow of electricity because they have more room to operate, therefore leading to greater efficiency. Polycrystalline PV cells, on the other hand, are rectangular and more affordable but less visually appealing and efficient than their counterparts. Instead of a single crystal structure, polycrystalline consists of many silicon fragments melted together to form wafers [Bla13]. Because of the increased number of crystals in each cell, the released electrons have less freedom to move and generate less current and energy. In general, both forms of crystalline PV technology show lots of potential to be deployed at a large scale due to their efficiency, durability, market share, and easy scalability (mentioned later).

The other form of PV cell is thin-film cells, which can be commercial (cadmium telluride, amorphous silicon, copper indium gallium diselenide) or new (perovskites). As their name suggests, these technologies are much thinner and lighter compared to their water-based counterparts. Generally, thin-film technology is composed of micron-thick, photosensitive photon-absorbing material layers deposited over a flexible substrate (can be glass, which is less expensive, or plastic and foil, which are both more expensive but allow for higher voltage modules to be created) [Cho04]. This is the primary difference between PV and thin-film solar cells, as the layers are much thinner and, therefore, easier

to break and less efficient. The primary advantages of thin-film cells include much lower costs and better building integration [Cho04]. Today, there are four viable types of thin-film PV cells available: amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and the latest innovation perovskites, all of which are placed in the thin semiconductor layer to convert sunlight into electrical power.

This paper will not discuss the varying technologies between these four forms in great detail, just a more general overview. To start with, amorphous silicon is the noncrystalline form of solar cells for thin-cell applications. Amorphous silicon cells generally have lower efficiency than other technologies (as do most forms of thin-film technology) but are one of the most environmentally friendly photovoltaic technologies since they do not utilize any toxic metals like lead or cadmium [Pau81]. This technology was once expected to become one of the significant contributors to the PV market but has since lost popularity after facing intense competition from the increased development of crystalline silicon cells mentioned earlier. Next, cadmium telluride cells have the smallest carbon footprint, lowest water use, and lower costs than conventional solar cells made of silicon and any thin-film PV technology [Pen13]. That said, the toxicity of cadmium is an environmental concern during the production and disposal of solar panels, therefore limiting production and usage. Thirdly, copper indium gallium diselenide is the newest innovation to come from thin-film solar cell technology. These cells are manufactured by depositing a thin layer of copper, indium, gallium, and selenium on the substrate. These materials have very high absorption rates and, therefore, can generate more electricity than other sources, outperforming polysilicon at the cell level, although they still have a lower module efficiency due to a less mature upscaling [Cho04]. The last kind of thin-film cell is the newly developed perovskites (named after their crystal structure). Like other thin-film technologies, these cells are built with layers printed onto the underlying support layer [Pen13]. These technologies have improved faster than any other PV material and have the potential to reach efficiencies similar to crystalline silicon.

Overall, crystalline PV has the most potential for rapid deployment and utilization in our society between these technologies. The other forms mentioned above, namely thin-film cells, are less efficient than water-based cells, and therefore on a broader scale, would not work as well. Current thin-film companies are surviving but face limited growth in the coming years. These water-based cells, on the other hand, specifically crystalline silicon cells, are both more durable (hold a longer lifespan), less expensive, and more efficient than other forms of solar currently being utilized or developed, therefore making it one of the more important technologies moving forward [Ahm18].

2.4 Stand-Alone vs. Grid Connected PV Systems

Zooming out from these specific technologies, like solar thermal, photovoltaic systems (which incorporate both water-based and thin-film technology) are generally categorized and applied into two main groups: (i) stand-alone and (ii)

grid-connected systems. Stand-alone systems, also called off-grid systems, are the systems that are not connected to the grid, and energy produced by the system is usually matched with the energy required by the load [Mek11]. They are usually supported by energy storage systems such as rechargeable batteries to provide electricity when there is no sunlight. Essentially it is a system that produces electrical power to charge banks of batteries during the day for use at night. The system consists of one or more PV modules, conductors, electrical components, and one or more loads [Mek11]. This PV system is ideal for remote areas and applications where other sources are impractical or unavailable. Stand-alone PV systems do not necessarily have to be located on building structures or rooftops for domestic applications but can also be attached to boats, tents, RVs, and so on for more everyday use. In general, the primary advantage of the stand-alone systems is that it is best suited for the developing and non-developed countries, as it is the only source of solar energy not dependent on a public grid location or access. The disadvantages include operational costs via maintenance and repair, which often depend on the power extracted from the PV panels [HA0].

On the other hand, grid-connected systems are the systems that are connected to the public grid. This kind of connection removes the dilemma by stand-alone systems. Using a concept called "net metering," grid-connected PV systems demand energy from the grid when there is not enough power generation on the panels and feed-in power to the grid when there is more than necessary power by the system, creating a constant balance [Mek11]. The primary component in a grid-connected PV system is the inverter, which converts DC (direct current) power produced by PV array into AC power consistent with the utility grid's voltage and power quality requirement, allowing them to operate in parallel [Mek11]. This form of PV and solar technology has seen increased popularity and development over the past couple of decades, as it is now being utilized in most developed countries around the world. The grid-connected system's primary advantages are that it requires little to low maintenance and economically makes more sense than the stand-alone system (financial incentives, smaller investment, better system design) [Ada14]. The main disadvantage is the lack of electricity storage due to no battery bank within the system. In general, however, grid-connected systems are preferred for larger scale utilization and deployment of solar (particularly in more prominent countries like the US or China) than stand-alone systems, which are more suited towards isolated regions.

2.5 Comparison of PV and Thermal Solar Technologies

Taking a step back to compare thermal and photovoltaic technologies, especially in light of recent development, PV, specifically the crystalline silicon mentioned above, has the most potential for rapid deployment and scalability in the coming decades. Because solar thermal is dedicated to heating water and air, solar PV has an obvious advantage in that it generates electricity, which is more critical on the broader scale of solar farming to stop greenhouse gas emissions (more

GHGs are emitted through electricity generation than warming water). This also allows solar PV owners to sell excess electricity back to the grid and generate a sustainable second income [Tri02]. Additionally, although traditionally solar thermal has been cheaper than PV, the recent Feed-In-Tariffs passed by the government changed that to offset the price differential and make the two systems comparable. Solar thermal systems are quite good on the smaller scale, take up less room on roofs than PV systems, and have more dispatchable generators (they are better at storing energy during the night), but again, in terms of bigger solar farms, PV, specifically crystalline silicon cells, has the highest potential of any solar technology for rapid deployment and utilization on the TerraWatt scale. Essentially, the solar technique that is most effective depends upon the purpose, setting, and application of that technology.

2.6 General Comparison: Solar to other Renewable Sources

Taking an even broader step back, it is important to compare solar energy to other renewables already mentioned in this paper. Before mentioning the advantages, solar, like any energy source, has some disadvantages as well. The most obvious of these is the reliance on the sun, which cannot be controlled and tends to have a periodic and dilute nature in many areas around the world. Because most solar technologies are relatively ineffective at producing electricity without direct access to the sun (during the nights or cloudy/rainy days), they are left relatively inefficient. This weather-dependency is less of a problem in desert regions in continents like Africa, but, like wind, can be an intermittent source and therefore an issue for electrical production in major cities on the coast like San Francisco, New York, or Boston. Additionally, solar's installation cost is very high compared to other renewable energy sources, although considering low maintenance costs (maintenance typically constitutes cleaning the cells or fixing any breaks to the technology) and high durability, that investment is likely to be offset in the long run.

That said, solar energy in all capacities (PV, Thermal, Stand-Alone, Grid Connected) has several significant advantages over other renewable energy sources. To start with, despite having high installation costs, solar requires less maintenance and holds greater durability than sources like wind and hydroelectric. This means that once the panels are installed, there is limited work to be done afterward, which is a big bonus to consumers worldwide. This, compared to the extensive maintenance required for wind turbines or hydroelectric power plants, offers a significant advantage to solar energy. Additionally, because solar does not require land otherwise used for crops of the environment, it holds less environmental damage than other sustainable energy forms like geothermal, biomass, tidal, or wind which use larger amounts of land. Of course, larger solar power plants need to be placed in open regions, but easy placement panels on roofs or in back gardens hold much less environmental impact and keep the energy source directly connected to homes. This is also related to Solar's scalability, as the energy source holds much more potential for widespread use than others that require specific environments (tidal or wind as an example).

Next, in light of recent technological developments surrounding PV crystalline silicon cells, the energy source is becoming more and more efficient in its energy production. Considering solar energy's potential to harvest the Earth's leading energy source, high energy production and storage efficiency are critical, and the current trajectory is promising. Finally, solar energy also produces no noise in generation, providing another advantage over large power plants used in other renewable energy production. All of these factors are why solar is considered one of the most promising renewable energy sources and will continue to be so in the future.

2.7 Examination of Current Economics and Social Renewable Energy Constraints

Now that it is clear that the basic premise of renewable energy is advantageous, and the technological development to back it up is getting stronger and more efficient, what is stopping us from using these effective and efficient technologies, not just solar, but all of the renewable energy at the scale we need them? In order to answer this question, I examined some of both the economic and social constraints that currently limit the necessary utilization of renewable energy sources worldwide.

The two most prominent constraints this paper focuses on for businesses are the far-reaching embedding of carbon in supply chains, operations, products, and services, alongside a lack of regulated economic carbon pricing. First, the deep embedding of carbon within supply chains, operations, products, and services severely limits the ways companies can transition towards a net-zero carbon industry. Analysis by Richard Heede at the Climate Accountability Institute finds that just 20 firms are behind of all carbon emissions, and 100 companies are behind 70 percent of all emissions, with notable names including Chevron, Exxon, BP, and Shell, all oil producers [Hee19]. As previously mentioned in the introduction, oil and gas drilling, obtained through underground pumps, releases pollutants into the atmosphere, which is then worsened by the further utilization and burning of these products in petroleum-based services such as transportation (airplanes, cars, trucks, etc.). The majority of the companies that are currently limiting the use of renewable energy or sustainable sources in their models are overly focused on personal profits. Because their environmentally costly models have been successful in the past, many are reluctant to change, even in light of recent climate change research. Much of this resistance occurs from the oil and gas sector, whereby powerful companies are not taking enough responsibility toward lowering their carbon footprint and becoming more sustainable. Also, because companies constantly emit carbon outside of mere product production (oil, gas, energy) through transportation services and other company interactions, the current emission of carbon dioxide is much higher than just the product. Instead, it relates to the entire model of the industry. In order to affect a switch to a more sustainable business model, companies first have to recognize their own embedded carbon footprint within their products, services, and operations and then make the changes necessary

to limit their emissions by setting goals and changing practices.

Additionally, a lack of regulated economic carbon pricing – an instrument that captures the external cost of greenhouse gas emissions – across all industries means that certain companies are not paying for the amount of carbon they are emitting. In today's global economy, certain companies can use and emit much more carbon than others without paying the appropriate price for their environmental damage, de-incentivizing any further change in their models [Tuk08]. Again, to ensure a successful transition to a renewable system, companies have to pay for the amount of carbon they use, and this payment system needs to be regulated across all industries. Although some believe that regulating carbon pricing will not reduce emissions, recent studies have shown that it is effective. Because companies are under more pressure to save money and waste needless expenditure, regulated carbon pricing works by shifting production and consumption from carbon-intensive systems to lower-carbon alternatives and reducing emissions. There are currently two ways a carbon price can be implemented: a carbon tax or a 'cap-and-trade' system. A carbon tax is simply a tax levied on all services and products that emit carbon in production, increasing the incentive to not emit carbon in key systems [Rit20]. On the other hand, a cap-and-trade system is one where the carbon price changes over time. A maximum target for pollution is defined, and manufacturers need licenses to emit carbon, the expense of which is determined by a trading system. The price of a license increases as a company's emissions approach the cap, thereby creating an economic incentive for reducing emissions and not paying larger amounts for more services [Rit20]. These systems work by increasing the price of a product as carbon emissions increase, resulting in products with a low carbon footprint remaining inexpensive, while goods with high carbon emissions increase expenditure.

The systems of carbon pricing help reduce emissions by both incentivizing the transition to and innovation of low-carbon technologies. Companies and producers use carbon pricing to save money by opting for cheaper low-carbon alternatives, developing these alternatives to reduce costs even further. Therefore, carbon pricing makes it more likely to rely on low-carbon products over fossil fuels, such as conducting a Zoom call over taking a flight or biking instead of driving [Rit20]. That said, there is currently no regulated carbon price for each industry, making it challenging to regulate environmentally harmful practices from major firms. In the future, regulated carbon pricing will be an essential factor in spur innovation and become more sustainable.

Both of these constraints (carbon embedding and lack of carbon pricing regulation) are some of the leading reasons why companies are not changing their carbon models at the necessary pace or efficiency to incorporate renewable solutions (energy, transportation, etc.), and show that there is still a way to go before we are ready to make the appropriate changes to our economic system.

Of course, certain companies are starting to change their models and practices to reduce their carbon footprint and become more sustainable moving forward. For example, members of the C2ES Business Environmental Leadership Council (BELC), which includes companies such as Amazon, Microsoft,

Shell, and Toyota, have recently committed to climate action and supporting renewable systems as they look to help in our fight against human-produced emissions. These companies aim to implement renewable strategies in operations and supply chains, such as investing in renewable energy or setting CO2 emission baseline reduction goals for the coming decades [fCS19]. For example, Microsoft is reducing its emissions by putting an internal price on carbon and reinvesting those dollars into clean power, energy efficiency projects, and carbon offset projects. In addition, Shell, one of the leading global CO2 emitters, launched a program in 2017 dedicated to reducing its net carbon footprint, recognizing the need to make internal improvements and external ones through those associated with the use of its products [fCS20]. Luckily, this trend of companies realizing the environmental damage of the current economic models and then looking to change something about it (by investing in sustainable sources or working on transportation) is increasing. Utilities such as the National Grid are engaging with their consumers to educate them on the importance of energy reduction, launching an energy efficiency and solar marketplace that allows its consumers to receive rebates for installing energy-efficient heating and cooling equipment and receive free quotes for solar installations and financing options [fCS19]. These changes proposed around these varying industries hold strong potential to lower our global carbon footprint and create more renewable energy systems. However, for renewable practices, ranging anywhere from solar energy to efficient modes of transportation, to be incorporated at the scale and speed necessary, more companies have to adopt these goals and change their models, focusing on the heavy carbon emitters.

On the other side of things, our society also has to make some changes to become more renewable. It is not simply the businesses or firms producing these carbon-emitting products, but also us as a society who are using them, only worsening their impact. As a general society, most of us are not very environmentally conscious regarding our daily habits and decisions, which need to change. The most prominent forms of poor constructs include inefficient modes of transportation, recycling, and food consumption, alongside a rise in consumeristic habits.

To start with, most of our transportation systems currently emit mass amounts of carbon dioxide into the atmosphere. Because over 90 percent of the fuel used for transportation services comes from petroleum-based sources, whenever people take planes or cars to move around, they emit CO2 by burning those fuels. Of course, transportation is necessary to operate daily, but the demand and usage of transportation are increasing, reinforcing a need for localization. According to the [Age], in the U.S. transportation sector alone, 1.9 billion tons of CO2 was emitted in 2019, amounting to 29 percent of all emissions in the country. Additionally, it is estimated that by 2035, 2-3 billion cars will be on the road, waiting for parking, going long and short distances, only worsening the problem. To make matters worse, the way we use cars is inefficient. It is too often the case that people are electing to drive themselves inefficiently, opting for a single-use drive (the average number of people in a car in the United States in 2017 was 1.5) or wasting time by circling for parking, emitting more harm-

ful pollutants than necessary [Age]. These actions increase each individual's carbon footprint without finding other means of collective, low-carbon impacts modes of transportation such as busing or biking. These statistics demonstrate that the current social utilization of cars, planes, and trucks needs to change for global emissions to reach the labels necessary to reverse the human impacts on the planet.

Additionally, the ineffective recycling, food, and general consumer systems are another constraint limiting our ability to transition to a sustainable future. Today, most items thrown away are placed into landfills, which in turn emit landfill gases (LFG) as a natural byproduct of the material's slow decomposition. As of the most recent Inventory Report, U.S. landfills released an estimated 114.5 million metric tons of carbon dioxide equivalent or methane into the atmosphere in 2019 [Age]. Also, the trash that is not placed into landfills often ends up in the environment, most commonly in oceans or lakes, which disturbs the ecosystems living there, and harms the planet further via water pollution. According to the International Union for Conservation of Nature, it is estimated that nearly 8 million tons of plastic end up in the ocean each year, harming marine life through a possibility of entanglement or digestion, and also threatening our food supplies, general health, and contributes to climate change [IUC18]. Therefore, to stop these excess emissions, recycling practices have to be advertised and practiced globally. Recycling helps lower carbon emissions and saves energy, which, as we know, is itself an indirect positive thing for our planet. Recycling items use a lot less energy than creating those same objects again, thereby lowering pollutants. Recycling and reusing materials more broadly are crucial to limit waste which is otherwise harder to deal with, as it stops the unnecessary emission of carbon and destruction of the environment.

Finally, the agricultural industry is also a large aspect of human-produced emissions, as the sector releases significant amounts of methane, nitrous oxide, and carbon dioxide. Methane is naturally produced by livestock, commonly cows, during digestion and can be stored in manure and organic waste, while nitrous oxide is an indirect product of organic and mineral nitrogen-based fertilizers [Smi07]. Additionally, there are several inefficiencies within agriculture, most notably poor irrigation and soil extraction systems. Although there have been some recent developments with the onset of drip irrigation, the current and most widely used irrigation systems within farming practices are highly inefficient at watering crops, thereby wasting water. Also, the carbon sequestration from soil extraction releases further carbon dioxide into the atmosphere, as the soil dug up is located in a soil carbon pool and therefore releases that carbon when extracted [Smi07]. Both of these systems need to be sustainably managed in order to help lower further carbon emissions. The transportation industry also multiplies these emissions, carrying the goods around in trucks and planes, increasing GHG emissions. The current societal demand for these products is a leading factor in our carbon footprints, as the rates of livestock production and consumption continue to rise, which only increases the rates of these emissions as farms need to produce more crops [Smi07]. In turn, these consumeristic habits, which relate to meat consumption and general consumption of environ-

mentally harmful goods, have also increased in the last 50 years. More people purchase goods with high carbon footprints or negative environmental connotations simply to satisfy their needs, such as fashion items, plastic-based gifts, or advanced technologies. The majority of people's basic needs are already met by the time of purchasing these goods (housing, clothing, etc.), and therefore this excess consumption can only hold a negative output.

In order to lower our carbon footprint, therefore, our global society needs to make some significant modifications regarding many of our ordinary habits, practices, and needs. This could include adopting a diet that is not meat-based and instead relies on products with lower carbon embedding, recycling more, opting to bike or share a ride with others than driving alone or simply localizing our lives. The onset of recent technological innovations surrounding diets through companies such as Impossible Foods or Beyond Meat or transportation with electric vehicles is helping to reduce these emissions. However, societal practices have to change to allow for the highest possible output from this development. As is frequently expressed within The Well-Tempered City by Jonathan Rose, for these habits to be implemented at the scale required, everyone needs to adopt them [Ros16]. It has been proven that the more people within a community practice beneficial actions such as these, the more likely the rest of the community is to follow suit. Therefore, changing the behavior within major cities should be increasingly adopted to effect a wider change. More people have to start criticizing companies for the carbon-intensive models and then looking within to make personal adjustments in their diet and modes of transportation. It is currently the case that the majority of the world lacks this culture of collectivism, but in order to make the changes we know to be crucial by adopting renewable solutions through energy, transportation, or food, we must begin to find ways of implementing these changes.

3 Primary Conclusions and Recommendations

The development of this paper shows both the importance of renewable energy systems, with some specific analysis of various technologies, along with a particular emphasis on the intricacies of solar energy, comparing it to some of the other sources mentioned previously. The paper's opening started by reviewing the major challenge our planet faces: increased reliance on fossil fuel consumption to produce forms of energy and then proposed a current solution to that problem: energy that does not use fossil fuels or renewable energy. There was then a brief, high-level discussion of some of the most prominent sources currently emerging from that field, including hydropower, wind, biomass, geothermal, and tidal/riverine, examining the significant technologies and advantages and disadvantages associated with each. After that information was established, the research focused on solar energy specifically, providing a much more detailed analysis of the various technologies and implementations of the energy source before speaking to how it compares to other forms of renewable energy. To briefly recap, one of the most prominent forms within solar energy was grid-connected

PV silicon cells, as the higher efficiency, durability, and scalability of the technology meant that it held the most potential for rapid deployment on a grander scale. Outside of those specifics, solar was highlighted as a high-potential source for similar reasons. Despite the reliance on weather conditions limiting productivity, the energy source can be space-effective, environmentally friendly, and highly efficient compared to other sources (wind, geothermal, biomass, etc.). Finally, the paper concluded by examining some of the current constraints facing the broader implementation of renewable sources into our economy and society. Here, the analysis finds that the far-reaching embedding of carbon in corporate supply chains, operations, products, and services, the lack of regulated carbon pricing, and poor societal constructs/systems (ineffective modes of transportation, recycling (food and water), and food consumptions for example) are some of the main obstacles that need to be addressed if solar, and renewable energy more broadly is to be effectively incorporated into business and social systems.

From here, it is important to understand why this research is necessary and what changes can be made in the future to help solve the problem. Renewable energy sources can completely transform our economy and society into a much more sustainable system and thus play a key role in lowering carbon emissions and the planet's temperatures. Therefore, to adopt this beneficial model, these systems need to be effectively incorporated into current business and social practices. This includes recognizing what needs to change within those habits (using excess carbon in transportation, product services, diets, operations, supply chains, etc.) and making the necessary adjustments to become more sustainable. The incorporation and implementation of renewable sources have to be both timely and efficient, as the quicker these energy sources replace fossil fuels, the closer we get to dramatically lowering global emissions. Additionally, there is a need for regulated carbon pricing to keep companies responsible for the amount of carbon currently being used in supply chains and operations. These policy and model adjustments are necessary to manage the incorporation of renewable energy sources and allow for more sustainable business practices.

Outside of economics, several societal factors can contribute to a more sustainable world. First, a strong, coherent, and knowledgeable social dialogue would allow these sources to gain more attention and force companies to adopt their models. Captivating young leaders like Greta Thunberg and wise climate activists such as David Attenborough are currently working to do precisely that, but for these renewable sources to achieve their potential, current and future generations will need them to advocate and challenge existing systems. Companies also need to play a role in this, as it is one thing to recognize their practices as unsustainable, but it is another to enact real change to their models. The stakeholders (companies, governments, consumers, and investors) must play a role in scaling, innovating, and implementing these technologies effectively to create a more sustainable world.

This research is only a fundamental review of the renewable energy sector, but the work highlights the importance and potential for the challenges we face to be overcome. As stated by David Attenborough in his latest documentary A Life on Our Planet, "no matter how grave our mistakes, the living world will

endure – we humans cannot presume the same" [Att20]. For the human population to survive and continue living on this planet, our lifestyles and habits have reached a point of mandatory adjustment. Technological innovations such as renewable energy sources and practical modes of transportation need to be effectively implemented into both our economy and society, with everyone playing their part to transition to a more sustainable world. Based on the current utilization of energy worldwide, the number of fossil fuels emitted into the atmosphere will soon (and already has in some areas) cause the planet to experience dramatic changes, impacting millions of lives and livelihoods across all countries and regions. There is no longer time to sit back and wait for something to change. The time for change is now, and a lot of that starts with incorporating renewable sources (energy, food, transportation) into societal and economic models. However imperfect our current relationship with nature may be, it is not all doom and gloom. If we can muster the will to become more sustainable, utilizing the enormous potential of this planet, living in balance with nature and its resources is most certainly a feasible feat, and there is great hope in that.

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