LEVERAGING SOLAR ENERGY SOURCES IN OREGON

by

Joseph Overdorf

A Directed Research Project

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science

School of Engineering Technology

West Lafayette, Indiana

April 19, 2021

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Professor John H. Dickey, M.A., D.H.L., CDRP Committee Co-Chair

Dr. Duane D. Dunlap

Purdue University, School of Engineering Technology

Approved by:

Dr. Duane D. Dunlap

Chair of the Graduate Program, School of Engineering Technology

To the entire Purdue University staff, I would not be successful as a student without your patience and willingness to work with me.

ACKNOWLEDGMENTS

I would like to thank the following people for supporting me throughout my life: my mother, father, and siblings Ashley, Jacob, Alex, Daniel, and Simon. My family has encouraged me in every adventure I have pursued. I would also like to thank my girlfriend, Mollie, for reviewing my deliverables, encouraging me, believing in me, and being patient with my busy schedule during my master’s program. Lastly, I would like to thank my best friends Hunter, Richard, Conrad, Keegan, Jake, and Louis. Our friendship means everything to me. I appreciate all of you for providing me an outlet from my daily responsibilities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

C	Carbon
CO_2	Carbon Dioxide
F	Fahrenheit
kWh	Kilowatt-Hour
lbs	Pounds
MWh	Megawatt-Hour
NAE	National Academy of Engineers
O	Oxygen
PPM	Parts per Million
PR	Performance Ratio
PV	Photovoltaic
ROI	Return on Investment

GLOSSARY

Carbon Dioxide – One important heat-trapping gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions (NASA, 2021)

Carbon Sequestration – Securing carbon dioxide to prevent it from entering the Earth's atmosphere (Climate Change, 2020)

Electron – A stable subatomic particle with a negative charge (Helmenstine, A., 2020)

Fossil Fuel – Non-renewable resources that formed when prehistoric plants and animals died and were gradually buried by layers of rock (Energy, n.d.)

Greenhouse Gas – Gases that trap heat in the atmosphere (EPA, 2020)

Kilowatt-hour - A unit of work or energy equivalent to 3.6 million joules (WhatIs, 2006)

Photon – A particle of light defined as a discrete bundle of electromagnetic energy (Jones. A, 2018)

Photosynthesis – The process used by plants, algae and certain bacteria to harness energy from sunlight and turn it into chemical energy (Vidyasagar, A, 2018)

Photovoltaic – Generating electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors (Solar Energy Industries Association, n.d.)

Semiconductor – Any class of crystalline solids intermediate in electrical conductivity between a conductor and an insulator (Britannica, 2021)

Solar Cell – Any device that directly coverts the energy of light into electrical energy through the photovoltaic effect (Fonash, R, n.d.)

ABSTRACT

Author: Overdorf, Joseph E. MS
Institution: Purdue University
Degree Received: April 2021
Title: Leveraging Solar Energy Sources in Oregon
Committee Chair: Dr. Duane Dunlap

The growing levels of carbon dioxide present an opportunity to find new ways of creating energy. The state of Oregon currently depends on fossil fuels to generate the electricity that other renewable energy sources cannot produce. Fossil fuels, such as coal, make up roughly 45.86% of the State of Oregon's electricity production (Energy in Oregon, 2018). One approach to reduce reliance on fossil fuels is to leverage the use of solar energy. Leveraging solar energy sources in Oregon is directly linked to the NAE Grand Challenge of "Developing Carbon Sequestration Methods" (National Academy of Engineering, 2019). Intel is one of the largest manufacturers in Oregon and possess the resources to switch from fossil fuels to exclusively solar energy. Relying exclusively on solar energy, Intel could reduce Oregon's carbon dioxide production between 9.98% and 14.97%. The amount of avoidable carbon dioxide is dependent on the solar array operating performance ratio. The concern with Intel relying exclusively on solar energy is the amount of space needed to install a solar array large enough to support Intel's demand.

Keywords: solar energy, carbon dioxide, carbon sequestration, fossil fuels

CHAPTER 1. INTRODUCTION

1.1 The Problem

The growing levels of carbon dioxide (CO_2) present an opportunity to find new ways of creating energy. Carbon dioxide is a greenhouse gas: a gas that absorbs and radiates heat gradually (Lindsey, 2020). Human caused greenhouse gases come from burning fossil fuels (U.S. Energy Information Administration, n.d.). Increasing levels of carbon dioxide continue to trap heat which raises Earth's average temperature (Lindsey, 2020). Currently, 80% of the world's energy originates from fossil fuels with oil accounting for 32.8%, coal 27.2% and natural gas 20.9% (Höök, 2013). The state of Oregon currently depends on fossil fuels to generate the electricity that other renewable energy sources cannot produce. The research study will further describe how renewable energy sources could be installed to reduce Oregon's dependence on fossil fuels. Carbon dioxide (CO_2) forms during coal combustion when one atom of carbon (C) unites with two atoms of oxygen (O) from the air (Hong & Slatick, 1994). Carbon dioxide levels will continue to grow if fossil fuels are used to generate energy. Unfortunately, the fossil fuels we rely on for energy are not easily replenished. Based on U.S. coal production in 2019 the recoverable coal reserves would last about 357 years (U.S. Energy Information Administration, 2020). One approach to reduce reliance on fossil fuels is to leverage the use of renewable energy.

Renewable energy, referred to as clean energy, comes from natural sources or processes that are constantly replenished (Shinn, 2018). There are a variety of renewable energy, biomass, solar, wind, tidal, and geothermal power, and that each source has advantages and drawbacks (Zohuri, 2018). Solar energy is the most abundant energy source on Earth (Marsh, 2019). Because of solar energy abundance, this research report is focused on how solar energy can offset fossil fuel use.

Solar power, referred to as photovoltaics (PV), is one of the most popular, and fastest-growing, sources of renewable energy (Zohuri, 2018). The PV effect is when incoming sunlight strikes a solar cell and knocks electrons loose, setting them in motion and generating an electric current that is captured through wiring (Marsh, 2019). Multiple cells make up a solar panel, and multiple panels wired together form a solar array (SunPower, n.d.). The more panels you can deploy, the more energy you can expect to generate (SunPower, n.d.). The current that is created by the PV effect provides energy instead of using energy created by fossil fuels. Companies can also benefit from photovoltaic solar energy generation by installing solar arrays that can power company operations or supply energy to the electric grid (Marsh, 2019). Company or residential solar arrays supplying energy to the grid is called "net metering". Net metering is a solar incentive that allows you to store energy in the electric grid (EnergySage, n.d.). The surplus energy, stored in the grid, will generate kilowatt hour credits that will be applied to future electric bills (Energy Trust of Oregon Inc, 2019). Just another incentive to leverage solar energy usage over fossil fuels in Oregon.

1.2 The Impact

Due to current CO_2 emissions, the number of days in Oregon resulting in extreme temperatures will increase by thirty days a year by mid-century (Floyd, 2019). Carbon dioxide concentrations are rising because of the fossil fuels that people are burning for energy (Lindesy, 2020). The annual global average carbon dioxide concentration at Earth's surface was 409.8 ± 0.1 parts per million (ppm), an increase of 2.5 ± 0.1 ppm over 2018 concentration (Blunden & Arndt, 2020). If global energy demand continues to grow and to be met by fossil fuels, atmospheric carbon dioxide is projected to exceed 900 ppm by the end of this century (Lindsey, 2020). Since carbon dioxide radiates heat, growing levels of carbon dioxide can cause Earth's average temperature to increase.

Since the use of fossil fuel took off during the industrial revolution, we have warmed the planet by about three quarters of a degree Celsius (1.35 F) (Berners-Lee & Clark, 2015). The incremental temperature increase is not noticeable since we experience temperature changes several times a day (Berners-Lee & Clark, 2015). Oregon is projected to warm by 4-9 degrees (F) by 2100 if global emissions follow the current path (Floyd, 2019). The warming projection would be altered and positively impacted if Oregon reduces the amount of fossil fuels that are used to generate energy.

1.3 Measurement of the Problem

The problem is measured by comparing utilization of Oregon utility company photovoltaic energy rates with fossil fuel rates determining carbon emission impacts. Fossil fuels, such as coal, make up roughly 45.86% of the State of Oregon's electricity production (Energy in Oregon, 2018). While 54.14% of Oregon's electricity is generated from renewable energy sources, only 1.33% of that is from solar energy (Energy in Oregon, 2018). Utility data shows that Oregon has the opportunity to reduce fossil fuel usage by increasing solar energy systems within the state. Specifically, how Oregon's industrial sector can take the initiative to install solar energy and reduce carbon dioxide production.

The first step was to determine Oregon's industrial sector energy usage. Then narrow down the focus to the energy usage of one of Oregon's manufacturing facilities. Energy reports from the manufacturer were used to determine the correct size of solar energy system needed to power the facility. The final step was to calculate the return on investment (ROI) to entice the company to pursue this investment. Using the energy reports from the manufacturer were also used to determine an estimated reduction in carbon dioxide production.

1.4 Ties to the National Academy of Engineering’s Grand Challenges

Leveraging solar energy sources in Oregon is directly linked to the NAE Grand Challenge of “Developing Carbon Sequestration Methods” (National Academy of Engineering, 2019). Carbon sequestration is capturing the carbon dioxide produced by burning fossil fuels and storing carbon safely away from the atmosphere (NAE Grand Challenge for Engineering, n.d.). By relying on solar energy, Oregon can contribute to carbon sequestration goals by not creating carbon dioxide. Although using solar energy does not create carbon dioxide, photovoltaic energy achieves the goal of not adding to existing carbon dioxide levels in the atmosphere.

1.5 Summary of the Problem Statement

Currently, 80% of the world’s energy originates from fossil fuels with oil accounting for 32.8%, coal 27.2% and natural gas 20.9% (Höök, 2013). Oregon is projected to warm by 4-9 degrees (F) by 2100 if global emissions follow the current path (Floyd, 2019). The focus of the research report was on Oregon’s ability to use solar energy to achieve carbon sequestration. Fossil fuels, such as coal, make up roughly 45.86% of the State of Oregon's electricity production (Energy in Oregon, 2018). Focusing on Oregon’s industrial sector, estimated amounts of carbon dioxide were calculated if Intel relied solely on solar energy.

The amount of fossil fuels used in Oregon is expected to impact the temperature of the state. Calculating photovoltaic output needed to supply Intel facilities and operations can be used to determine the amount of avoidable carbon dioxide production. The following chapters explained how carbon dioxide production will be reduced if Oregon’s Intel campus converts their energy generation to solar power.

CHAPTER 2. REVIEW OF LITERATURE

2.1 History of Solar Energy and Carbon Dioxide Levels

Sunlight has been a part of Earth since the beginning of time. Plants using sunlight in photosynthesis has driven the curiosity of what else sunlight can do. The French physicist A. E. Becquerel observed the photovoltaic effect for the first time in 1839 (Fessler, 2019). He discovered that electricity is created when photons knock an electron free from an atom. Figure 2.1, below, shows how the photovoltaic effect works.

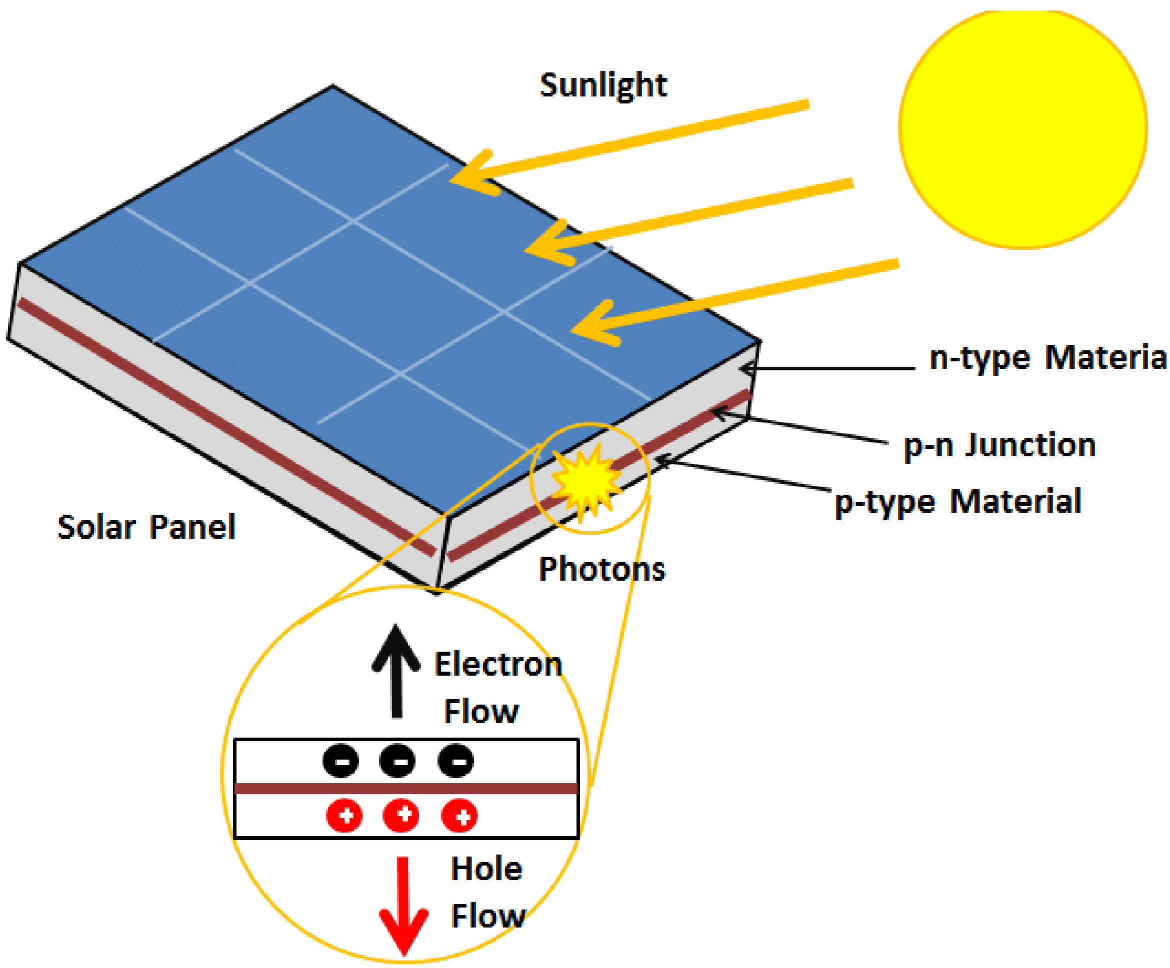


Figure 2.1: Photovoltaic Effect (Hanania, Stenhouse, & Donev, 2015)

Figure 2.1, on page 6, shows how photons from sunlight separates electrons from atoms and the moving electrons create a current of electricity. Solar panels were not commercialized until years later. By the 1950's, Bell Laboratories realized that semiconducting materials such as silicon were more efficient (Chu & Tarazano, 2019). Bell Laboratories was able to create a solar cell that achieved six percent efficiency (Chu & Tarazon, 2019). The discovery of semiconductor material efficiency was the start of the modern solar panel. In 1956, Hoffman Electronics acquired the patent, from Bell Laboratories, for solar panels in the United States (Jones and Bouamane, 2012). Hoffman Electronics solar panels were applied to satellites (Jones and Bouamane, 2012). The Vanguard 1 was the first solar powered satellite sent to space in 1958 (Eschner, 2017). The solar panels on the Vanguard 1 only produced one watt in total (Jeppesen, 2018). In comparison, the iPhone holds a charge of 5.45-watt hours (Helman, 2015). The Vanguard 1 validates that solar energy is a viable energy source for applications.

Atmospheric carbon dioxide levels have increased approximately 25% from 1800 to 1985 (Trabalka, J., & United States. Department of Energy, 1986). Carbon dioxide concentrations are rising because of the fossil fuels that people are burning for energy (Lindesy, 2020). Figure 2.2, on page 8, illustrates how carbon dioxide levels in the atmosphere have increased along with the increase of carbon dioxide emissions.

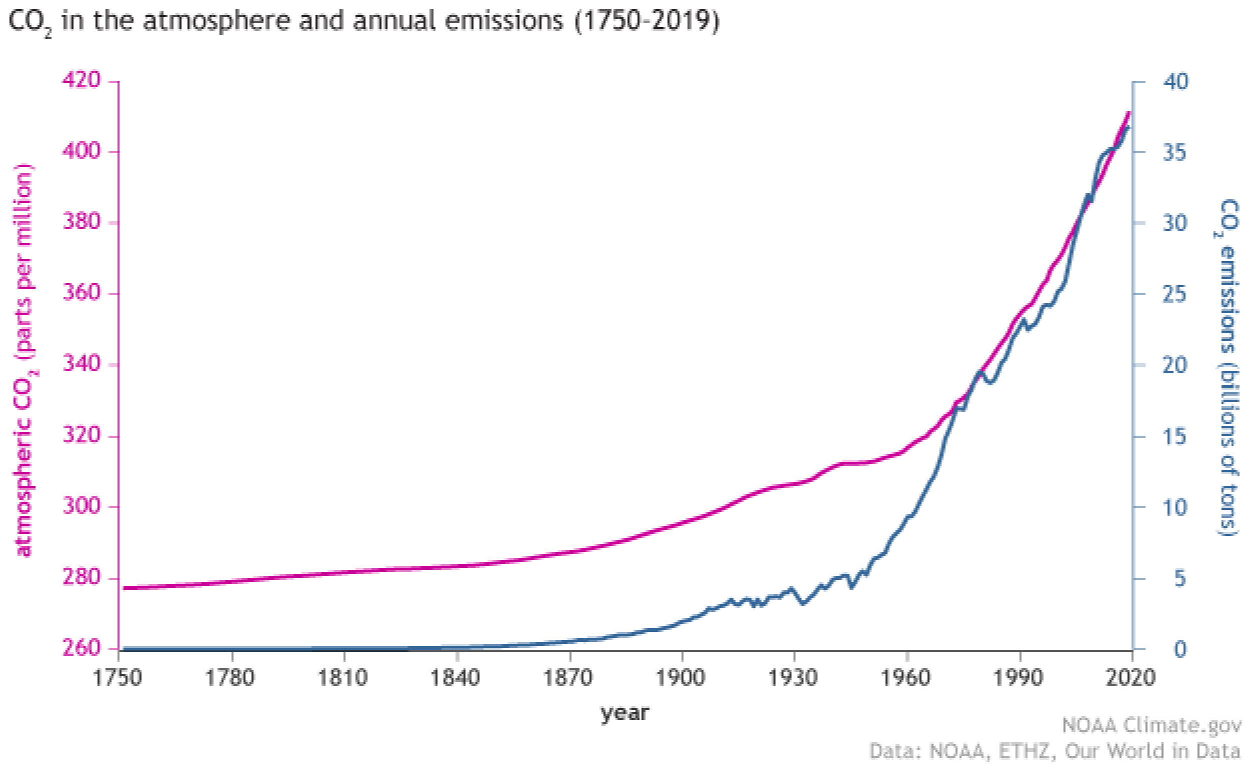


Figure 2.2: Carbon Dioxide Levels by Source Through the Years (Lindsey, 2020)

Figure 2.2 illustrates carbon dioxide levels, atmospheric in purple and emissions in blue, with the year along the horizontal axis in black. The data shows that atmospheric and emissions levels of carbon dioxide continue to grow as the years pass. Thanks to Lindsey, the researcher recognized that carbon dioxide absorbs and radiates heat gradually (2020). So, if the carbon dioxide levels are increasing does this mean the Earth's temperature is increasing? Figure 2.3, on page 9, shows that the Earth's temperature is, in fact, increasing.

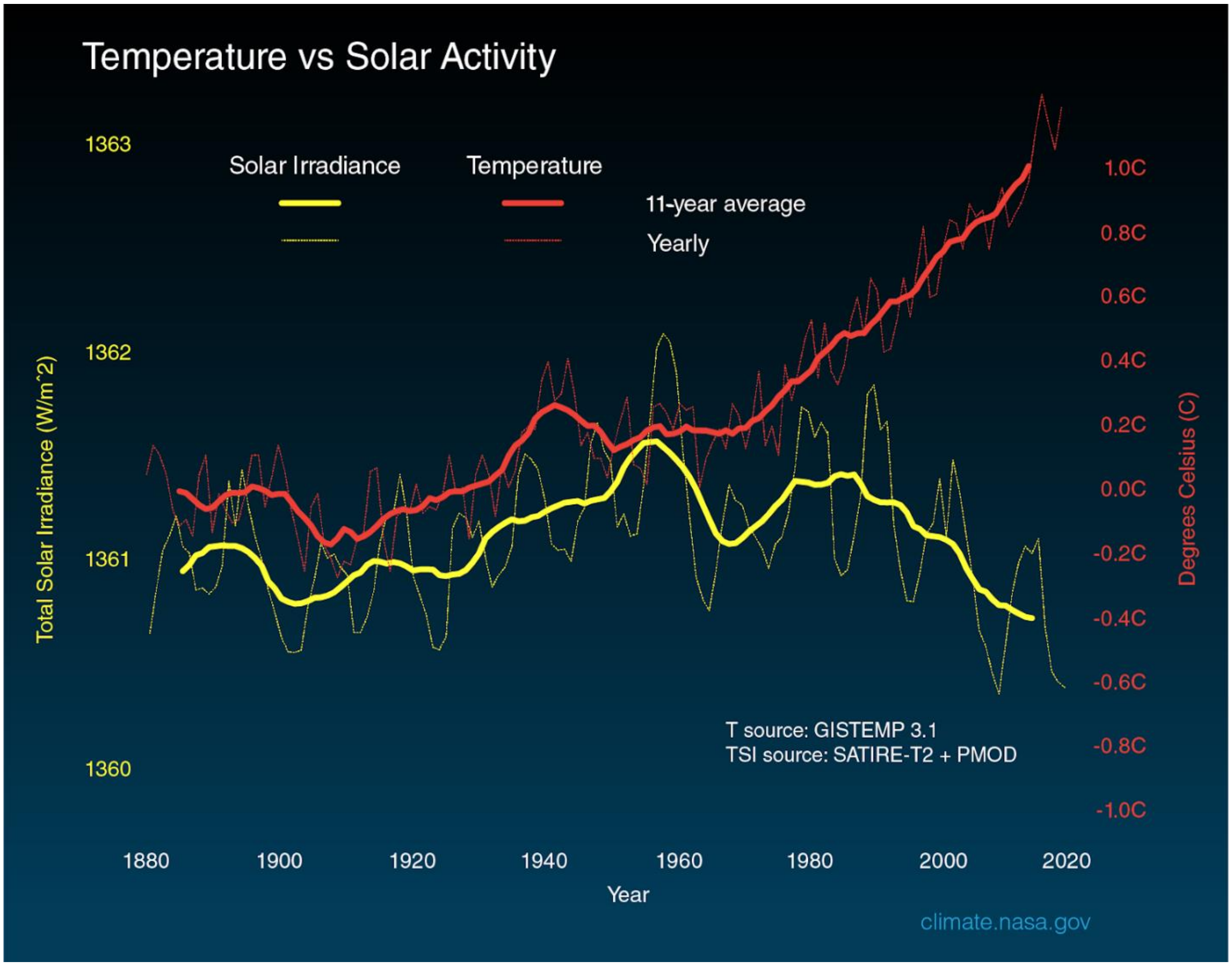


Figure 2.3: Global Surface Temperature and Sun's Energy Received (NASA, 2020)

Figure 2.3 illustrates the global surface temperature (red) and the Sun's energy that Earth receives in watts per square meter (yellow). The amount of solar energy that Earth receives has followed the Sun's natural 11-year cycle of ups and downs (NASA, 2020). Over the same period, global temperature has risen markedly (NASA, 2020). Therefore, Figure 2.3 supports that there is global warming happening. The global warming is assumed to be from the heat that the increased levels of carbon dioxide have absorbed and gradually released.

2.2 Oregon Power Generation and Consumption

Oregon has currently generated roughly 28% of the state's electricity from nonrenewable energy sources, as shown in Figure 2.4, below, (U.S. Energy Information Administration, 2020). There have been 1.639 million Megawatt-Hours (MWh) produced that have created emissions, as illustrated in Figure 2.4. If the energy generation trend continues for every month of the year, there would be 19.668 million MWh of electricity generated from nonrenewable energy sources (Figure 2.4). In 2018 Oregon's industrial sector consumed 25.3% of all generated energy, as shown in Figure 2.5, on page 11, (U.S. Energy Information Administration, 2020).

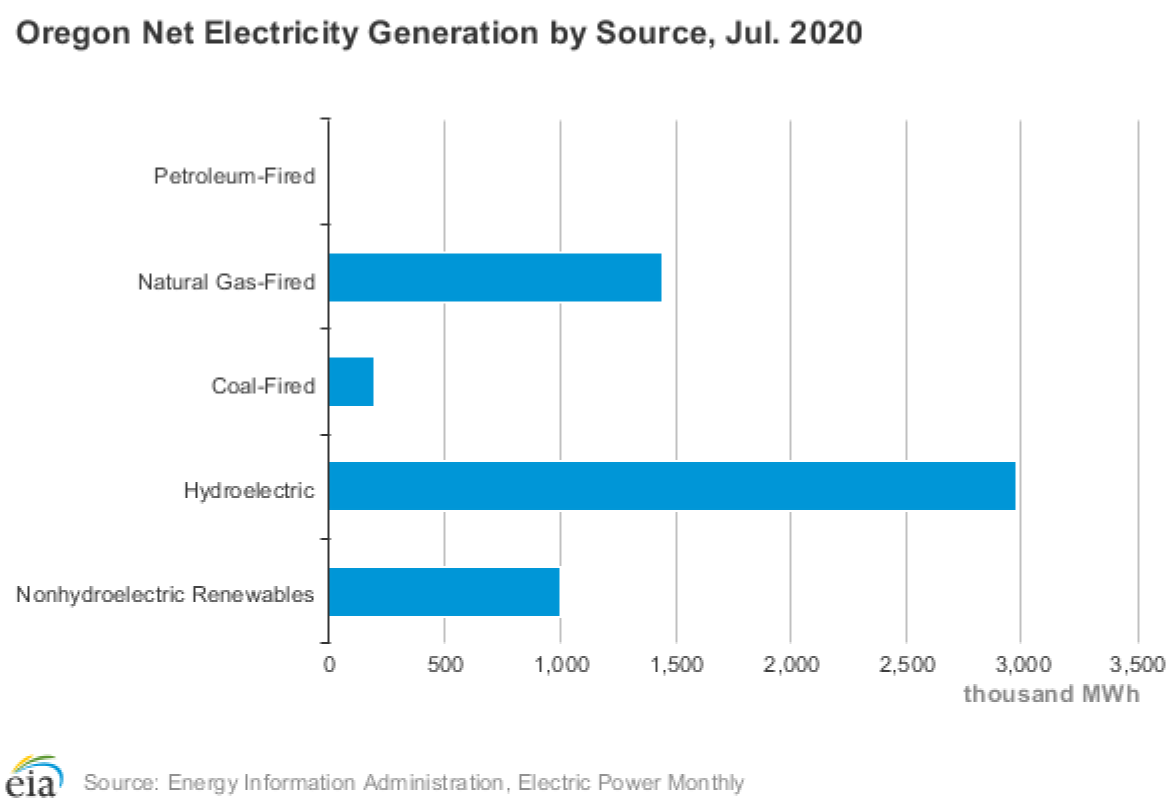


Figure 2.4: Oregon Net Electricity Generation by Source (U.S. Energy Information Administration, 2020)

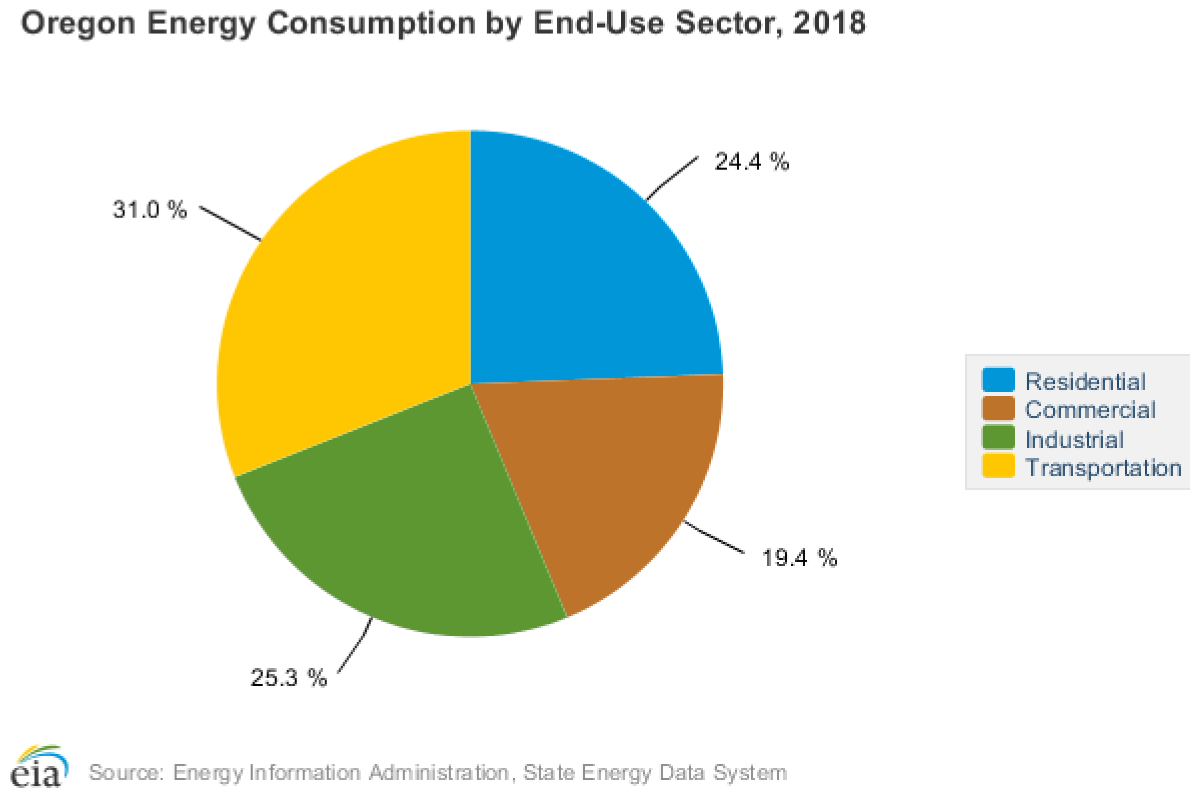


Figure 2.5: Oregon Energy Consumption by End-Use Sector (U.S. Energy Information Administration, 2020)

Focusing on one company in Oregon's industrial sector provides the opportunity to determine the potential impact of solar energy. The below figures, Figure 2.6, 2.7, 2.8, and 2.9, on pages 12 – 13, highlight and describe Intel's energy usage in the last year. The data shows that Intel used 2.25 million MWh from July 2019 to June of 2020. Figure 2.6, on page 12, highlights and describes Intel's Oregon campus' energy usage in the third quarter of 2019. Intel's Oregon campus used 530,643,917 kWh worth of energy in the third quarter of 2019.

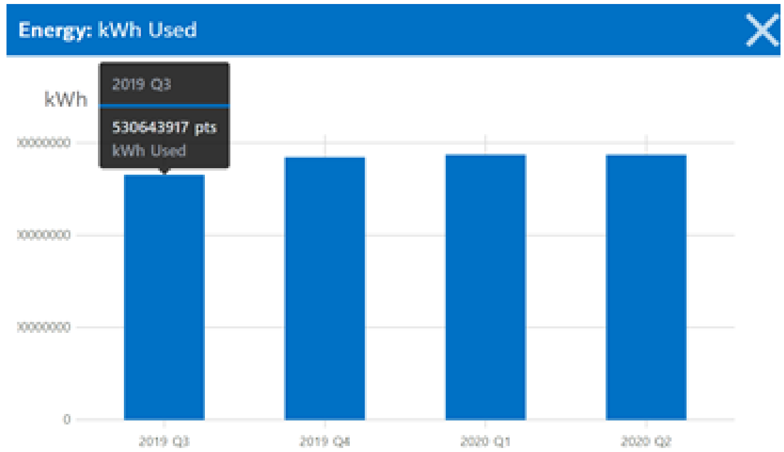


Figure 2.6: Intel Energy Usage in Quarter Three of 2019 (Intel Corporation, n.d.)

Figure 2.7, below, highlights and describes Intel’s Oregon campus’ energy usage in the fourth quarter of 2019. Intel’s Oregon campus used 568,986,450 kWh worth of energy in the fourth quarter of 2019.

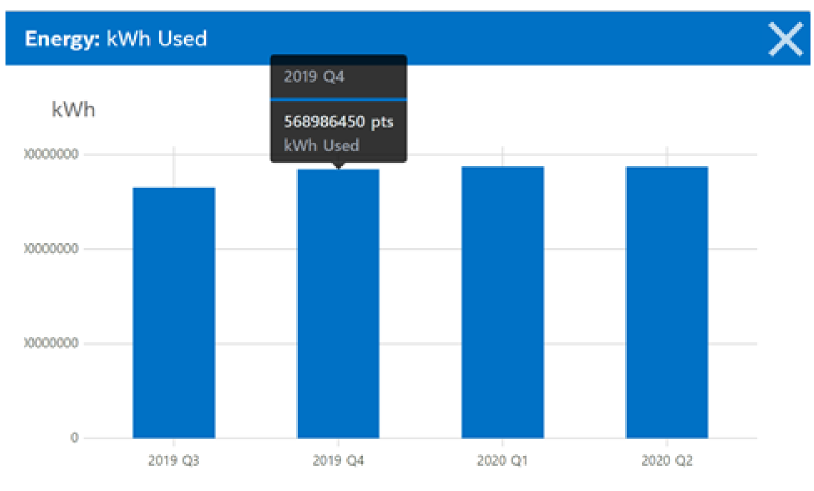


Figure 2.7: Intel Energy Usage in Quarter Four of 2019 (Intel Corporation, n.d.)

Figure 2.8, below, highlights and describes Intel's Oregon campus' energy usage in the first quarter of 2020. Intel's Oregon campus used 574,818,625 kWh worth of energy in the first quarter of 2020.

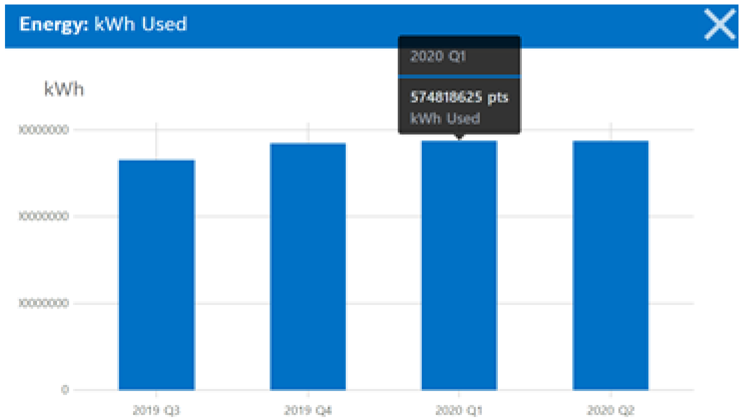


Figure 2.8: Intel Energy Usage in Quarter First of 2020 (Intel Corporation, n.d.)

Figure 2.9, below, highlights and describes Intel's Oregon campus' energy usage in the second quarter of 2020. Intel's Oregon campus used 574,552,158 kWh worth of energy in the second quarter of 2020.

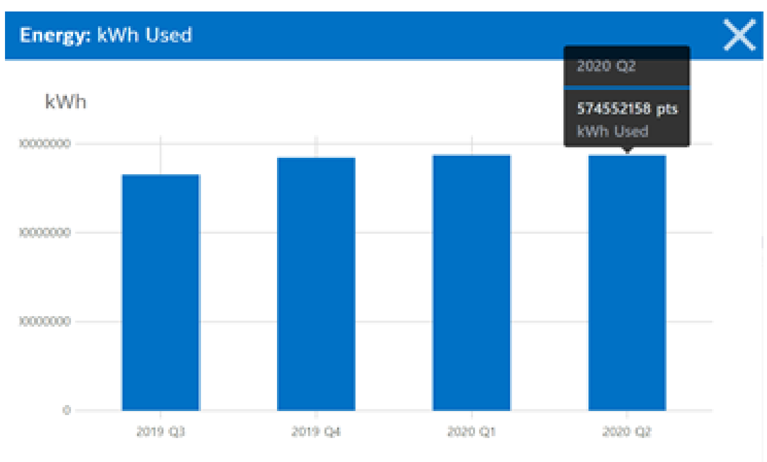


Figure 2.9: Intel Energy Usage in Quarter Two of 2020 (Intel Corporation, n.d.)

Figure 2.4, on page 10, shows the how much electricity each specific source generates for the State of Oregon. Figure 2.8, on page 13, shows Intel's energy consumption for the first quarter of 2020. Figure 2.8 shows Intel's highest, quarterly, energy consumption in the past year. Intel's quarterly energy consumption can be used to calculate the potential reduction in fossil fuel reliance by Oregon. The four recorded quarters of Intel's energy usage, Figures 2.6, 2.7, 2.8, and 2.9, on pages 12 and 13, can be used to trend future energy demands. Reducing the amount of fossil fuel usage by the calculated amount would impact Oregon's carbon dioxide generation. Figure 2.10, below, shows the amount of carbon dioxide produced when generating one kWh of electricity.

U.S. electric utility and independent power electricity generation and resulting CO2 emissions by fuel in 2018

	Electricity generation	CO2 emissions		
	million kWh	million metric tons	million short tons	pounds per kWh
Coal	1,124,638	1,127	1,240	2.21
Natural gas	1,246,847	523	575	0.92
Petroleum	21,860	21	23	2.11

Electricity generation is net electricity generation.
Includes electricity-only power plants. Combined heat and power plants are excluded because some of their CO2 emissions are from heat-related fuel consumption.

Figure 2.10: CO_2 Emissions by Fuel Source in 2018 (U.S. Energy Information Administration, 2020)

The data provided in the above Figures, 2.4, 2.6, 2.7, 2.8, 2.9, and 2.10, on pages 10 – 14, was used to determine an estimated amount of avoidable carbon dioxide generation. Figure 2.4, on page 10, shows that Oregon relies primarily on natural gas when using fossil fuels to generate energy. Intel's historical data can be used to trend the company's future energy demands. Intel's future trend data can be used when determining how large of a solar array system to install.

Figure 2.10, on page 14, depicts how much carbon dioxide each fossil fuel produces when used to generate a kilowatt-hour of energy. The data in Figure 2.10, on page 14, is vital for calculating avoidable carbon dioxide produced if the state of Oregon relies more on solar energy. Again, avoiding the generation of carbon dioxide is one approach to accomplishing the goal of carbon sequestration.

2.3 Benefits of Solar Energy

A company, such as Intel, would benefit from their solar arrays if the company installed enough arrays. One of the benefits is through net metering. Net metering helps to offset the cost of the electricity you buy with energy you generate at your business (Portland General Electric, n.d.). If your qualifying facility has a nameplate capacity greater than 10 MW and you'd like to sell power, the power is bought under a negotiated power purchase agreement (Portland General Electric, n.d.). Any net metering that occurs can help to improve the return on investment (ROI) of the solar arrays. A second benefit is that solar energy is a clean energy. Using solar power, instead of fossil fuels, reduces the amount of carbon dioxide emitted into the environment (Department of Energy, n.d.).

2.4 Solar Photovoltaic Systems and Efficiency

To successfully harness sunlight to generate electricity, a solar photovoltaic system must be installed (Department of Energy, n.d.). Figure 2.11, below, illustrates the components of a complete photovoltaic system. The main components are the panel array, disconnects, power conditioning unit, connection to the main AC panel.

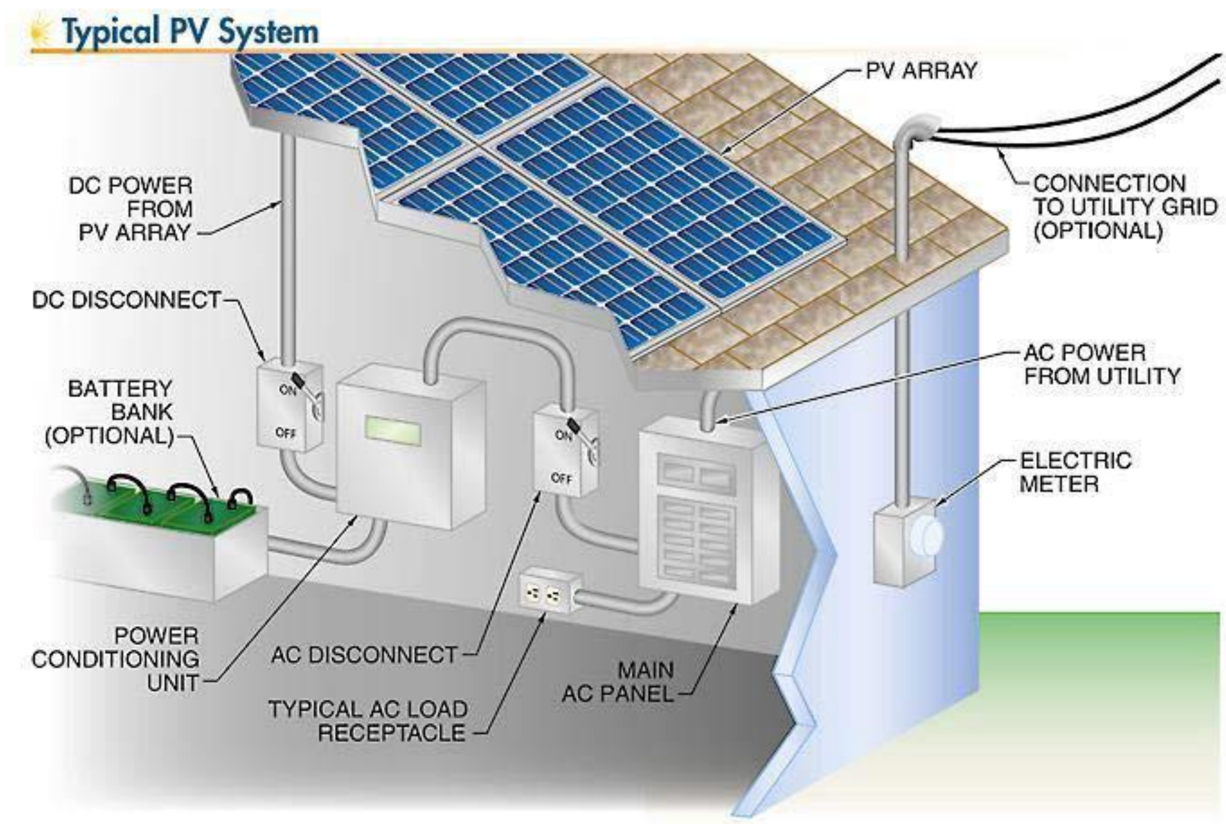


Figure 2.11: Components of a Solar PV System (Rexel Corporation, n.d.)

Consumers and people in the solar industry consider solar panel efficiency to be the most important criterion when assessing a solar panel's quality (Aggarwal, 2020). Current solar panels are between 15% and 20% efficient, with outliers on either side of the range (Aggarwal, 2020). SunPower panels are known for being the most efficient solar panel brand available on the market (Aggarwal, 2020). The SunPower 430–450W Commercial A-Series Panels operate at an average efficiency of 21.7% (SunPower, 2020). Additional data on the SunPower panels, provided by SunPower, is found in Appendix A. Due to the commercial application, and efficiency ratings, the SunPower 430-450W Commercial A-Series Panels were used for the research.

2.4.1 Sun Exposure

The amount of sunlight that reaches a solar array is vital to the production of electricity. More sun exposure results in more electrons are knocked loose by sunlight to create more electricity (Marsh, 2019). The amount of solar radiation that reaches the Earth's surface varies according to location, time of day, season, landscape, and weather (Office of Energy Efficiency and Renewable Energy, 2013). The below Figure, 2.12, shows the average sun exposure for the United States.

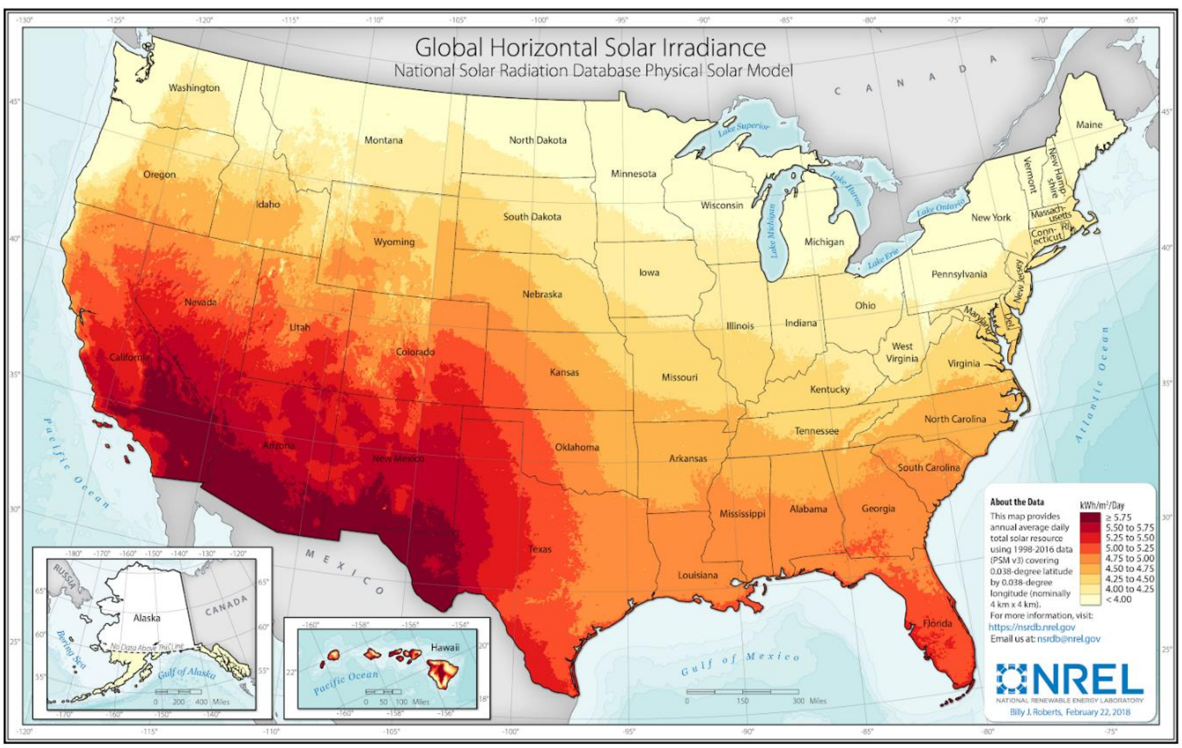


Figure 2.12: United States Average Annual Sun Exposure (Sengupta, et al., 2018)

Figure 2.12, on page 17, shows that Oregon receives an average of 4.25 - 4.50 sunlight hours per day. A visual comparison of Oregon to the rest of the country, in Figure 2.12, shows that roughly half of the country gets the same amount of sun exposure as Oregon.

2.4.2 Sizing Solar Arrays

Intel’s energy usage, described in Figures 2.6, 2.7, 2.8, and 2.9, and the sun exposure map (Figure 2.12) was used in determining the size of the solar array. The first assumption was that Intel’s highest quarter of usage, 574,818,625 kWh, Figure 2.8 on page 13, is the standard demand. The second assumption was that there are 4.25 sunlight hours, or global radiation value, per day. The final assumption was a 75% performance ratio during sunny days and 50% performance ratio for overcast days. The total surface area of one solar panel is 3,148 inches squared, which can be found in Appendix A. The efficiency rating is 22.2%, which can be found in Appendix A. The equation in Figure 2.13, below, will be used to determine the surface area needed to meet Intel’s energy demands. The surface area for Intel’s demand will then be divided by the surface area of a solar panel to determine the number of panels needed.

$$E = A * r * H * PR$$

E	total amount of energy (kW)
A	total surface area
r	efficiency rating
H	global radiation value
PR	performance ratio

Figure 2.13: Equation for Sizing Solar Arrays (Booth, 2020)

Figure 2.13, on page 18, shows the equation used to calculate the amount of energy each SunPower panel can produce. The next step was determining the number of panels needed to supply Intel's energy demand. The final step was determining if Intel's campus, Ronler Acres, had enough available space to support the number of panels required. Figure 2.14, on page 20, shows Intel's Oregon campus and the available space for installing solar panel arrays.

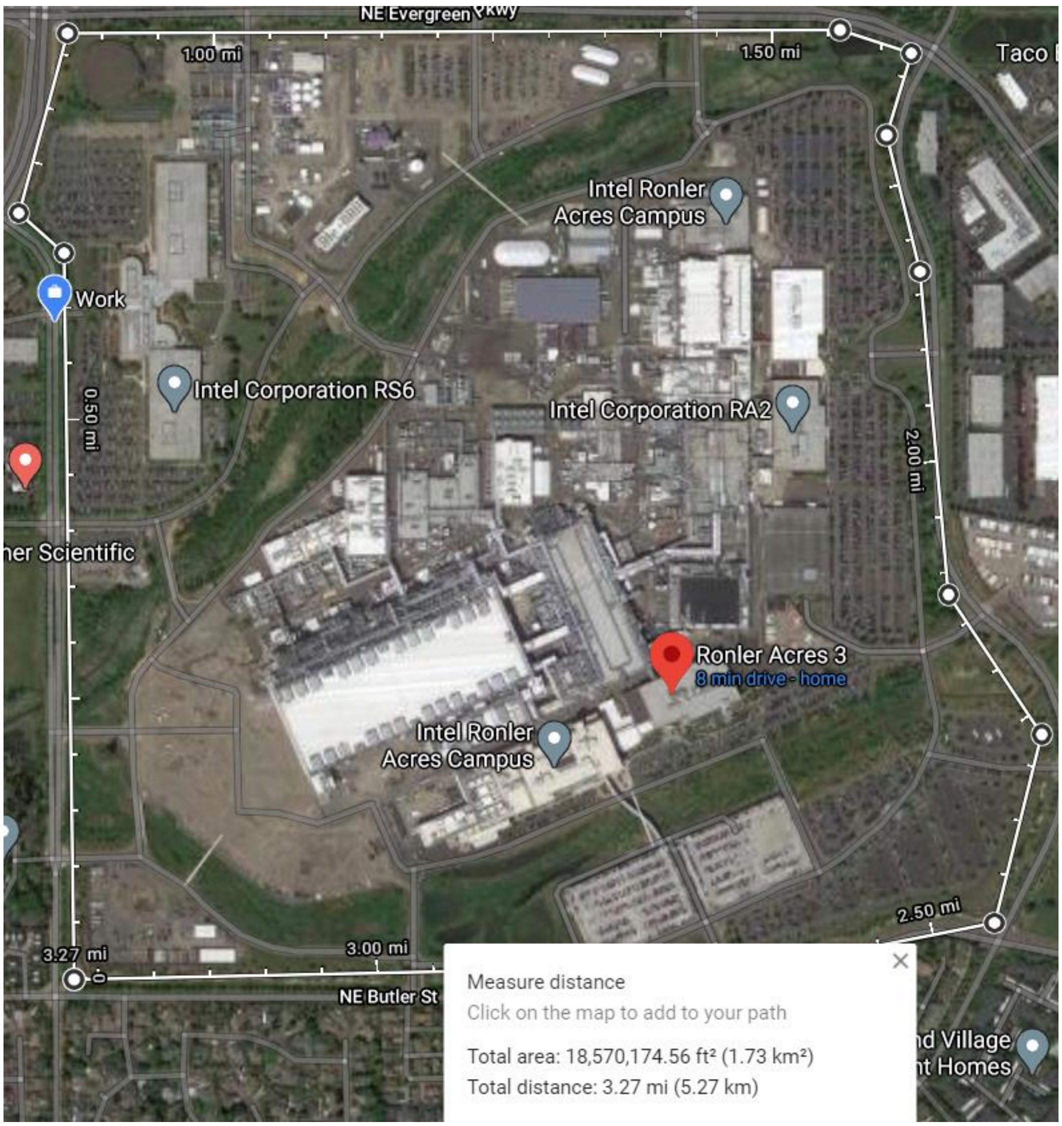


Figure 2.14: Intel's Ronler Acres Campus (Google, n.d.)

Figure 2.14, on page 19, shows the size of Intel's campus and potential locations for the solar arrays. The solar arrays would not have to be located together but spreading out the arrays would create additional installation costs.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research Methodology Overview

The Chapter Two, Review of Literature, research illustrated the impact that solar energy would have on Oregon's carbon dioxide production. Comparing Oregon's Industrial energy demands to fossil fuel usage provided insight on the amount of carbon dioxide production. The study focuses on Intel's energy usage and the amount of carbon dioxide that would be avoided if Intel relied on solar energy. Energy usage and generation was collected from Intel and the State of Oregon. The energy demand dictated the number of solar panels needed. Knowing the number of panels needed, the study included locating potential space for panel installation. After confirming viable space for the required panels, the amount of avoidable carbon dioxide was calculated. Calculating the avoidable carbon dioxide amount for Intel was compared to potential carbon dioxide avoidance for the state.

3.1.1 Research Environment

The research environment for the study was specific to Oregon. The test subject, Intel, is located in the suburbs of Portland, Oregon. Intel has one main manufacturing facility in Oregon, but three main manufacturing facilities in the United States. While the study focuses on Oregon, the application could be applied anywhere. The intention of the report was to validate solar energy as a means to reduce carbon dioxide production from energy generation.

3.1.2 Sample Population

The sample population was the State of Oregon and Intel. Oregon offers a variety of climate characteristics that are not commonly found in the United States. Oregon's limited sun exposure of 4.25-4.50 hours per day, referenced in Figure 2.12, on page 17, will challenge solar energy in ways that other states will not. Intel has campuses throughout the United States (Intel Corporation, n.d.). Including Intel's Ronler Acres as the sample population allows for this study to be replicated at other Intel locations.

3.1.3 Statistical Measures

The statistical hypothesis is straightforward since the study focuses on quantities. The null hypothesis (H_0) will be determined: Oregon's industrial sector can reduce the amount of carbon dioxide generated by installing their own solar arrays. The alternative hypothesis (H_A) was determined: Oregon's industrial sector is unable to install enough solar arrays to reduce the amount of carbon dioxide generated.

3.1.4 Limitations

The study has numerous limitations. Energy generation and consumption can be calculated if new introductions to the manufacturing facility are accounted for. Industrial expansion and or new machine efficiencies would influence energy demands. Industrial expansion allows for more manufacturing machines to be added which would drive greater energy consumption. Industrial expansions containing new technologies is usually sensitive information that is not shared outside of the company. Energy generated by solar arrays is expected to vary based on weather patterns.

3.2 Research Instruments

Research instruments included a kilowatt-hour meter to track energy consumption. The kilowatt-hour meter was installed by the local utility company to track month to month energy usage. The kilowatt-hour meter tracks the energy usage of the specific establishment that the meter is installed at. The kilowatt-hour meters are used to determining how much energy Intel uses. The U.S. Energy Information Administration data was used to capture carbon dioxide levels, percentage of energy sources used, and amounts of energy generation.

3.3 Procedures for Data Collection

The research focused on Oregon's industrial sector. Intel's Ronler Acres campus was used for collecting data. Ronler Acres is one of the largest manufacturing facilities in the state of Oregon. Intel and Ronler Acres were not chosen randomly, and the size and energy usage of the facility could not be controlled. Intel and Ronler Acres were chosen due to the researcher's connection to the site. The energy usage for the facility was the key data needed for researching how much solar energy is needed to power the facility. Intel's energy usage can be found online but only displays data for the past year.

After identifying the energy usage, the next step in the research was to determine if adequate space existed to install a solar array that can produce enough energy to meet the facility's demand. Google Maps was used to measure the size of the property where solar arrays could be installed (Google, n.d.). Google Maps allowed the researcher to get an aerial view of Ronler Acres and has a measuring feature for determining distances. Using Google Maps allowed the researcher to propose a viable location and verify that the proposed location was large enough. Using specifications from a predetermined solar panel, the researcher calculated the space needed to build a solar array large enough to produce the monthly energy demand. A solar panel submittal provided the panel specs needed for the energy production calculations.

Lastly, the minimum space needed for the solar array system and the amount of avoidable carbon dioxide production can be calculated. The minimum space needed was calculated by determining how many panels need to be installed. The number of panels can be calculated by taking the amount of energy that needs to be generated divided by the average amount of energy that one panel can generate. Once the number of panels was determined, the researcher can multiple the number of panels by the area of one panel. Multiplying the number of panels by the area of the panels determined the amount of space required. After the solar array energy output was calculated, the researcher calculated the amount of avoided carbon dioxide production. The researcher calculated the avoidable carbon dioxide by multiplying the carbon dioxide produced by generating 1kWh from natural gas by the amount of kilowatt hours Intel consumed. The amount of carbon dioxide calculated was the amount that the state of Oregon avoided generating for Intel's energy demand.

3.4 Presentation Data

The data was presented in a Table format as illustrated in Table 3.1 on page 25. The Table included the following:

- Title – Amount of Avoidable Carbon Dioxide in Oregon
- Units of Measure – Kilowatt hours (kWh), Pounds per Kilowatt hour (lb*kWh), and Percentage (%)
- Energy Demand – The amount of Kilowatt hours used, or demanded, in a month
- Amount of Energy Solar Panels Can Produce (Range based on PR influenced by weather and season) – The number of solar panels needed to produce enough electricity to meet the local demand.
- The Amount of Area Required – Surface area required for the solar array in square feet
- The Amount of Avoidable Carbon Dioxide – Oregon's avoidable carbon dioxide in tons
- Percentage of Oregon's Carbon Dioxide Production – The amount of avoidable Carbon Dioxide divided by Oregon's total Carbon Dioxide production

Table 3.1: Amount of Avoidable Carbon Dioxide in Oregon

Solar Array Performance Ratio (PR)	Intel's Monthly Energy Demand (MWh/month)	Number of Solar Panels	Surface Area Required (ft^2)	Amount of Energy Produced (MWh/month)	Amount of avoidable Carbon Dioxide Production (tons)	Percentage of Oregon's Carbon Dioxide Production (%)
Performance Ratio 50%						
Performance Ratio 75%						

The above Table, Table 3.1, presented the values calculated by the researcher. Table 3.1 was used to present all the data so that different scenarios could be compared.

3.5 Research Methodology Summary

The goal of the research was to determine whether Oregon's industrial sector can rely on solar energy to reduce the amount of carbon dioxide production. By locating energy consumption, a solar array was sized to support the energy demand. Since the solar array was sized and configured, the research calculated whether the array could support energy demands with a changing performance ratio. After validating the solar array, the reduction of carbon dioxide was calculated.

CHAPTER 4. RESULTS

4.1 Solar Analysis

The research results illustrated the number of solar panels and surface area needed to provide Intel with enough solar energy to meet the monthly demand. The results also illustrate the amount of avoidable carbon dioxide production for the state of Oregon. Additionally, the research calculated the energy production range using estimated performance ratios for the solar panels. Further research would be required to determine the actual performance ratio range of solar panels in Oregon. The performance ratio of a solar panel can be influenced by cloud coverage or debris covering the solar panels. Simply put, the performance ratio of a panel is the percentage of the operating energy generation to the designed energy generation. Intel’s Ronler Acres is Intel’s only manufacturing campus in Oregon. Energy demand information, gathered from Intel, determined the size of the solar array needed to reduce the maximum amount of carbon dioxide generation. The researcher calculated two scenarios using the lower and upper range of solar panel performance ratio. Scenario one used the lower range of the solar panel performance ratio was used to calculate the minimum number of solar panels needed to generate Intel’s monthly energy demand. Scenario two used the upper performance ratio was used to calculate the maximum amount of energy that could be generated using the minimum number of panels required to meet Intel’s demands.

4.2 Results Objective

The research intended to determine the amount of carbon dioxide generation that would be avoided if Intel relied on solar energy. By avoiding the generation of carbon dioxide, utilizing solar energy achieves the grand engineering challenge of carbon sequestration. The results showed that replacing Intel's monthly energy usage with solar energy would reduce Oregon's carbon dioxide generation significantly. The results showed the benefits when the solar array operates under ideal conditions.

4.3 Case Study: Intel's Ronler Acres Solar Array Performance

The first calculations used the most recent energy demand and usage data from Intel. Figure 4.1, below, shows that Intel used 574,818,625 kWh of electricity in the first quarter of 2020. The first quarter of a year consists of the months January, February, and March.

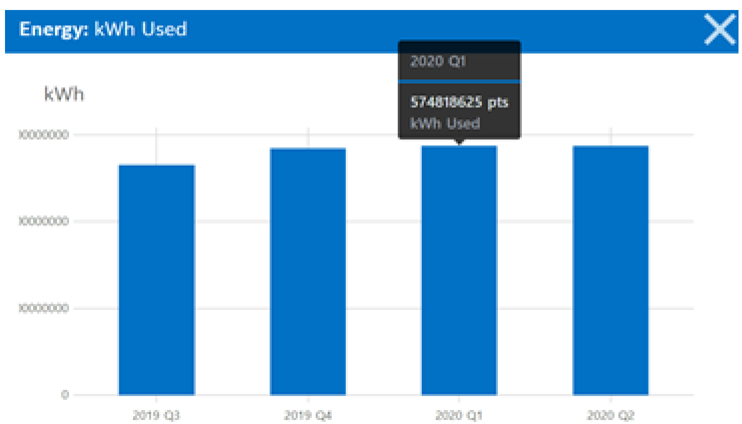


Figure 4.1: Intel Energy Usage in Quarter One of 2020 (Intel Corporation, n.d.)

The average monthly usage for the first quarter can be determined by calculating the mean, or average, of the total usage across the three months. Figure 4.2, on page 28, shows the calculation for determining Intel's average monthly electrical energy demand in the first quarter of 2020.

$$Average\ Demand\ (MWh) = \frac{574{,}818{,}625\ kWh}{3\ months} * \frac{1\ MWh}{1000\ kWh} = 191{,}606.208\ MWh/month$$

Figure 4.2: Average Monthly Demand Calculation

Intel's monthly energy demand of 191,606.208 MWh/month, calculated in Figure 4.2, above, was used in both scenarios of calculating the number of solar panels needed. The two scenarios that were calculated illustrated the difference the solar panel efficiency has on the number of panels and space needed to meet a required energy demand.

4.3.1 Scenario One: 50% Solar Panel Performance Ratio

Scenario one focused on calculating the number of solar panels needed to meet Intel's energy demand while the panels were operating at a 50% performance ratio. Intel's monthly energy demand of 191,606.208 MWh, calculated in Figure 4.2, above, was used to calculate the area required to install a solar array large enough to meet Intel's energy demand. The calculations for determining the area required for the solar array are presented in Figure 4.3, on page 29. The equation used for calculating the area required for the solar array contains variables that were provided by previous figures. Figure 2.13, on page 18, explained the base equation and variables used for calculating the required area. The variables needed for the equation are the efficiency rating, performance ratio, the energy demand, and the global radiation value. Appendix A provided the efficiency rating, 22.2%, for the solar panels. The research team chose the performance ratio of 50% for the calculations of the lower performance range. The total monthly energy demand was calculated in Figure 4.2, above, and represents the minimum amount of energy the solar array must produce to meet Intel's monthly energy demand. Global radiation value, or sun exposure, was determined to be 4.25 – 4.50 sunlight hours through Figure 2.12, on page 17.

$$Surface\ Area\ (m^2) = \frac{191{,}606.208\ MWh}{50\%\ (PR)*22.2\%\ (r)*(\frac{4.25\frac{kWh}{m^2}}{day}\ (H)*30\frac{days}{month}*\frac{1\ MWh}{1000\ kWh})} = 13{,}538{,}683\ m^2$$

Figure 4.3: Surface Area Required for Solar Array (Scenario One)

The surface area required for the solar array was calculated in meters squared but was converted to square feet (ft^2) in Figure 4.4, below, for the researcher's preference.

$$Squared\ Feet\ (ft^2) = 13{,}538{,}683\ m^2 * \frac{10.7639\ ft^2}{1\ m^2} = 145{,}729{,}171\ ft^2$$

Figure 4.4: Converting Surface Area Calculations (Scenario One)

The surface area of 145,729,171 square feet was used to calculate the number of solar panels needed to provide Intel's energy demands. Figure 4.5, below, shows the calculation to determine the necessary number of solar panels. The dimensions for the size of the solar panel are described in Appendix A. The solar panels are 78.7 inches long and 40 inches wide.

$$Number\ of\ Solar\ Panels = \frac{145{,}729{,}171 ft^2}{(40\ in * 78.7\ in) * \left(\frac{1 ft^2}{144\ in^2}\right)} = 6{,}666{,}135\ solar\ panels$$

Figure 4.5: Number of Solar Panel Calculations (Scenario One)

Figure 4.5, above, illustrates that 6,666,135 solar panels are needed to produce Intel's monthly energy demand. The number of solar panels required was calculated using the solar panels operating with a 50% performance ratio.

4.3.2 Scenario Two: 75% Solar Panel Performance Ratio

Scenario one calculated the number of solar panels required to produce enough energy to meet Intel's monthly demand while operating at a 50% performance ratio. Scenario two calculated the energy produced from the same number of solar panels operating at a 75% performance ratio. Intel's monthly energy demand requires a minimum of 6,666,135 solar panels, calculated in Figure 4.5, on page 29, to be installed to generate enough energy. The calculations presented in Figure 4.6, below, illustrate the amount of energy the minimum number of solar panels will produce with a higher performance ratio. Figure 2.13, on page 18, explained the base equation and variables used for calculating the energy generation of the solar array. The variables needed for the equation are the efficiency rating, performance ratio, the energy demand, and the global radiation value. Appendix A, on page 44, provided the efficiency rating, 22.2%, for the solar panels. The research team chose the performance ratio of 75% for the calculations of the higher performance range. The surface area of the solar panels required to meet Intel's energy demand was calculated in Figure 4.3, on page 29. Global radiation value, or sun exposure, was determined to be 4.25 – 4.50 sunlight hours as displayed in Figure 2.12, on page 17.

$$Total\ Energy\ Generation\ (MWh) = 22.2\%\ (r) * 75\%\ (PR) * \left(\frac{4.25\frac{kWh}{m^2}}{day}\ (H) * 30\,\frac{days}{month} * \frac{1MWh}{1000kWh}\right) *\ 13{,}538{,}683\ m^2\ =\ 287{,}409.317\ MWh$$

Figure 4.6: Maximum Energy Generated (Scenario Two)

Figure 4.6, on page 30, illustrated that the increased performance ratio resulted in an increased energy generation from the solar array system. When the solar array operated with a 75% performance ratio, the solar array produced 287,409.317 MWh each month.

4.4 Case Study: Avoidable Carbon Dioxide Generation

The next set of calculations aimed to determine the amount of avoidable carbon dioxide that would not be generated if Intel relied solely on solar energy. The first calculation determined the amount of avoidable carbon dioxide based on the energy produced from the solar panels operating at a 50% performance ratio. Figure 4.7, below, shows the calculation for carbon dioxide that will not be generated from a solar array operating at a 50% performance ratio. The equation for calculating the amount of avoidable carbon dioxide production required variables provided in previous figures. The equation required the rate of carbon dioxide production per kilowatt hour of energy produced and the amount of energy being generated. Figure 2.10, on page 14, provided the rate of 0.92 pounds (lbs) of carbon dioxide per kilowatt-hour generated from natural gas. The researcher chose natural gas due to Figure 2.4, on page 10, showing that Oregon relies on natural gas as the primary fossil fuel for generating electricity. Intel's monthly energy demand of 191,606.208MWh/month, calculated in Figure 4.2, on page 28, is the value for energy the solar array operating with a 50% performance ratio can produce in a month.

$$Amount\ of\ Avoidable\ Carbon\ Dioxide\ (tons) = 0.92\frac{lbs}{kWh} * \frac{1\ ton}{2000\ lbs} * \frac{1000kWh}{1MWh} * 191{,}606.208\ MWh = 88{,}138.86\ tons\ of\ Carbon\ Dioxide$$

Figure 4.7: Calculation for Avoidable Carbon Dioxide Operating with a 50% Performance Ratio

Figure 4.7, on page 31, illustrates that 88,138.86 tons of carbon dioxide generation would be avoided each month by Oregon if Intel relied exclusively on solar energy. Figure 4.7, on page 31, calculates the avoidable carbon dioxide production when the solar arrays operated at a 50% performance ratio. The next calculation, Figure 4.8, below, illustrates the amount of avoidable carbon dioxide when the solar array operated at the optimal 75% performance ratio. Figure 4.8, below, also requires the rate of carbon dioxide production per kilowatt hour of energy produced and the amount of energy being generated. Figure 2.10, on page 14, provided the rate of 0.92 pounds (lbs) of carbon dioxide per kilowatt-hour generated from natural gas. The solar array, operating at a 75% performance ratio, produced 287,409.317 MWh per month, as determined in Figure 4.6, on page 30.

$$Amount\ of\ Avoidable\ Carbon\ Dioxide\ (tons) = 0.92\,\frac{lbs}{kWh} * \frac{1\ ton}{2000\ lbs} * \frac{1000kWh}{1MWh} *$$
$$287{,}409.317\ kWh = 132{,}208.29\ tons\ of\ Carbon\ Dioxide$$

Figure 4.8: Calculation for Avoidable Carbon Dioxide Operating with a 75% Performance Ratio

Figure 4.8, above, illustrates that 132,208.29 tons of carbon dioxide generation would be avoided each month by Oregon if Intel relied exclusively on solar energy. Figure 4.8, above, calculates the avoidable carbon dioxide production when the solar arrays operated at a 75% performance ratio.

4.5 Case Study: Oregon’s Carbon Dioxide Generation

The last set of calculations determined the percentage of Oregon’s carbon dioxide production that would be avoided if Intel relied on solar energy. Calculating Oregon’s total carbon dioxide production required information provided in previous figures. Figure 2.4, on page 10, provided the data that Oregon generated 1.639 million MWh of electricity in July of 2020. Of that 1.639 million MWh, 1,439 thousand MWh were generated from natural gas and 200 thousand MWh were generated from coal. The calculation in Figure 4.9, below, illustrates the total amount of carbon dioxide Oregon generated in one month. Each fuel source produced a different amount of carbon dioxide per kilowatt hour of energy generated. Figure 2.4, on page 10, provided the values for carbon dioxide generated per kilowatt-hour by source. The carbon dioxide generation values are 2.21 lbs for coal and 0.92 lbs for natural gas.

$$Amount\ of\ Carbon\ Dioxide\ (tons) = \left(\frac{2.21 lbs}{kWh} * \frac{1\ ton}{2000 lbs} * 200{,}000{,}000 kWh\right) + \left(\frac{0.92 lbs}{kWh} * \frac{1\ ton}{2000\ lbs} * 1{,}439{,}000{,}000 kWh\right) = 882{,}940\ tons\ of\ Carbon\ Dioxide$$

Figure 4.9: Oregon’s Monthly Total Carbon Dioxide Generation Calculation

Figure 4.9, above, illustrates that Oregon produced a total of 882,940 tons of carbon dioxide in one month. Figure 4.10, below, and Figure 4.11, on page 34, illustrate that Intel using solar energy would reduce Oregon’s carbon dioxide generation based on the performance ratio that the solar array operated at. Operating at a performance ratio of 50%, the solar array would prevent the generation of 88,138.86 tons of carbon dioxide, as calculated in Figure 4.7, on page 31. Operating at a performance ratio of 75%, the solar array would prevent the generation of 132,208.29 tons of carbon dioxide, as calculated in Figure 4.8, on page 31.

$$Percentage\ of\ Oregon's\ Carbon\ Dioxide\ Generation\ (\%) = \frac{88{,}138.86\ \ tons}{882{,}940\ \ tons} * 100 = 9.98\ \%$$

Figure 4.10: Calculation for Percentage of Avoidable Carbon Dioxide (Lower Limit)

Figure 4.10, above, illustrates that Intel could reduce Oregon's carbon dioxide generation by 9.98% a month using a solar array operating at a 50% performance ratio.

$$Percentage\ of\ Oregon's\ Carbon\ Dioxide\ Generation\ (\%) = \frac{132{,}208.29\ tons}{882{,}940\ tons} * 100 =$$

$$14.97\ \%$$

Figure 4.11: Calculation for Percentage of Avoidable Carbon Dioxide (Upper Limit)

Figure 4.11, above, illustrates that Intel could reduce Oregon's carbon dioxide generation by 14.97% a month using a solar array operating at a 75% performance ratio.

4.6 Results Analysis

A summary of the lower and upper performance ratio scenario results is in Table 4.1, below. The table compiles the calculated data from sections 4.3 through 4.5.

Table 4.1: Leveraging Solar Energy at Intel to Achieve Carbon Sequestration for Oregon

Solar Array Performance Ratio (PR)	Intel's Monthly Energy Demand (MWh/month)	Number of Solar Panels	Surface Area Required (ft^2)	Amount of Energy Produced (MWh/month)	Amount of avoidable Carbon Dioxide Production (tons)	Percentage of Oregon's Carbon Dioxide Production (%)
Performance Ratio 50%	191,606.208	6,666,135	145,729,171	191,606.208	88,138.86	9.98%
Performance Ratio 75%	191,606.208	6,666,135	145,729,171	287,409.317	132,208.29	14.97%

Table 4.1, above, illustrates that Intel relying exclusively on solar energy would reduce Oregon’s carbon dioxide generation by 9.98% to 14.97%. The range of the percentage reduction is contingent on the operating performance ratio of the solar array. While the range for avoidable carbon dioxide is appealing, the surface area required for installing the solar array is problematic. The surface area of solar panels required to produce Intel’s energy demand was driven by the lower limit of the performance ratio. Figure 4.5, on page 29, illustrated that Intel’s Ronler Acres only offers 18,570,174 square feet of surface area. The surface area of 145,729,171 square feet for the solar array described in the research project is equivalent to 5.22 square miles, or 2,526.5 American football fields.

Table 4.1, on page 34, revealed a linear relationship between the performance ratio and the avoidable carbon dioxide production. When the performance ratio of the solar panels increased, the amount of avoidable carbon dioxide production increased. Table 4.1 also revealed a linear relationship between the performance ratio and the amount of energy produced by the solar panels. When the performance ratio of the solar panels increased, the amount of energy produced by the solar panels increased. The linear relationship to the performance ratio was verified by the equations used to calculate the avoidable carbon dioxide and amount of energy produced by the solar panels. The linear relationship is logical because when the weather is clear and sunny, the solar array will produce more energy. Subsequently, less carbon dioxide is generated when the solar array receives more sunlight.

4.7 Results and the Impact

The increasing levels of carbon dioxide production in Oregon present an opportunity to leverage solar energy to offset the generation of carbon dioxide. According to the National Academy of Engineering, one of the grand engineering challenges is to develop carbon sequestration methods (National Academy of Engineering, 2019). As one of the largest manufacturers in Oregon, Intel could make the switch to solar energy and have a significant impact on Oregon's carbon dioxide generation. The case study displayed that Intel relying on a solar array, operating in overcast conditions, would still reduce Oregon's carbon dioxide generation by 9.98%. A reduction of carbon dioxide generation by 9.98% would prevent Oregon from releasing 88,138.86 tons of carbon dioxide a month into the atmosphere. Under optimal weather conditions, a solar array supplying Intel's energy would prevent 132,208.29 tons of carbon dioxide generation a month.

The drawback to the proposal is the amount of space needed to install a solar array in Oregon large enough to meet Intel's monthly energy demands. Oregon's predominantly overcast climate, in addition to the efficiency of modern solar panels, requires an unrealistic amount of space to install an array that produces Intel's energy demand. Further research would be required, but the eastern half of Oregon contains the area needed to support the magnitude of solar array needed for Intel. Eastern Oregon is considerably less populated than the region where Intel is located. However, despite the space constraint, the results showed that solar energy can be leveraged to significantly reduce Oregon's carbon dioxide generation. As a result, all conclusions and recommendations will require further research. Further research will examine additional scope to ensure that leveraging solar energy to reduce Oregon's carbon dioxide generation is worthwhile. The further research will allow Intel, and other Oregon entities, to make data driven decisions about leveraging solar energy to reduce carbon dioxide generation in Oregon.

CHAPTER 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Overview

Renewable energy is a viable solution in the search for methods of reducing the generation of carbon dioxide. One of the most popular forms of renewable energy is solar energy. By relying on solar energy, Oregon can contribute to carbon sequestration goals by not creating carbon dioxide. Leveraging solar energy in Oregon is directly linked to the NAE Grand Challenge of "Developing Carbon Sequestration Methods" (National Academy of Engineering, 2019).

Oregon's industrial sector represents a large portion of the state's energy consumption and Intel is one of largest manufacturers in the state. The researcher analyzed the impact Intel had on Oregon's carbon dioxide generation by relying exclusively on solar energy. Through analyzing the energy production range of a solar array, Intel's impact was determine. While the solar array operated at a 50% performance ratio, Intel reduced Oregon's carbon dioxide production by 9.98%. Additionally, while the solar array operated at a 75% performance ratio, Intel reduced Oregon's carbon dioxide production by 14.97%. The groundwork for further research was identified by calculating the impact Intel would have on Oregon's carbon dioxide production.

5.2 Summary

One of the NAE Grand Engineering Challenge is the developing of carbon sequestration methods (National Academy of Engineering, 2019). Carbon dioxide is a greenhouse gas: a gas that absorbs and radiates heat gradually (Lindsey, 2020). Human caused greenhouse gases come from burning fossil fuels (U.S. Energy Information Administration, n.d.). Increasing levels of carbon dioxide continue to trap heat which raises Earth's average temperature (Lindsey, 2020). Renewable energy, such as solar energy, is a viable option for reducing the reliance on fossil fuels. By leveraging solar energy, Oregon can contribute to carbon sequestration goals by reducing the reliance on fossil fuels to generate energy. As one of Oregon's largest manufacturers, Intel was chosen as focal point of the research.

The research focused on the amount of carbon dioxide production Oregon would avoid if Intel relied exclusively on solar energy. The researcher analyzed the solar array operating at a 50% and 75% performance ratio. The range of the performance ratio displayed the impact weather conditions had on the solar array's energy production. The research showed that Intel reduced Oregon's carbon dioxide production between 9.98% and 14.97% by relying exclusively on solar energy. However, the research analysis discovered that Intel's campus is not large enough to support a solar array large enough to supply Intel's monthly energy demand. The discovery that Intel does not have enough space to support the entire solar array laid the groundwork for further research opportunities.

5.3 Conclusions

The results of the research illustrated the impact solar energy had on Oregon's carbon dioxide production. Relying exclusively on solar energy, Intel reduced Oregon's carbon dioxide production between 9.98% and 14.97%. Reducing carbon dioxide production by 9.98% to 14.97% prevents 88,138.86 tons to 132,208.29 tons of carbon dioxide a month. The range of avoidable carbon dioxide was driven by the solar panels operating performance ratio. However, the research results also illustrated that Intel's campus is not large enough to support a solar array capable of producing Intel's energy demand. Intel would need 145,729,171ft^2 of space to install a sufficient solar array. Without acquiring the required 145,729,171ft^2 to install a solar array, Intel would not be able to rely exclusively on solar energy. Additional research is necessary to determine the amount of avoidable carbon dioxide from utilizing the available space on Intel's campus. Sizing the solar array to Intel's available space would reduce Oregon's carbon dioxide generation but the amount was not calculated.

5.4 Recommendations for Future Work

The recommendations require additional research to determine the calculated impact or feasibility of the recommendation.

Those recommendations and reasoning are:

1. Look for a 145,729,171ft^2 location where a solar array large enough to produce Intel's energy demands could be installed.
    a. The eastern half of Oregon is less populated than the area where Intel's campus is located, meaning there is more open space.
    b. Eastern Oregon has higher sun exposure compared to Intel's location in western Oregon, as illustrated in Figure 2.12, on page 17. A higher sun exposure value translates to the solar array producing more energy.
2. Research alternative solar panels to determine if there are more productive solar panels.
    a. A more productive solar panel requires a smaller solar array to produce the same energy as the researched solar array.
3. Research the difference in the residential, commercial, transportation, and industrial energy sectors utilizing solar energy.

LIST OF REFERENCES

Aggarwal, V. (2020, July 12). Solar Panel Efficiency: What Panels Are Most Efficient?. Retrieved October 31, 2020, from https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/

Berners-Lee, M., & Clark, D. (2015). *The burning question: We can't burn half the world's oil, coal and gas - so how do we quit?* London: Profile Books.

Blunden, J., & Arndt, D. (2020, August 8). Takeaways Points from the State of the Climate. *State of the Climate in 2019*.

Booth, J. (2020, January 03). How Much Electricity Does A Solar Panel Produce Per Day? Retrieved October 31, 2020, from https://solarmonsters.com/help-advice/solar-panels-advice/how-many-kwh-does-a-solar-panel-produce/

Britannica. (2021, February 12). Semiconductor. Retrieved April 10, 2021, from https://www.britannica.com/science/semiconductor

Chu, E., & Tarazano, D. (2019, April 22). A Brief History of Solar Panels. Retrieved October 30, 2020, from https://www.smithsonianmag.com/sponsored/brief-history-solar-panels-180972006/

Climate Change. (2020, May 13). Carbon Sequestration. Retrieved April 09, 2021, from https://climatechange.ucdavis.edu/science/carbon-sequestration/

Department of Energy. (n.d.). Homeowner's Guide to Going Solar. Retrieved October 31, 2020, from https://www.energy.gov/eere/solar/homeowner-s-guide-going-solar

Energy in Oregon. (2018). Retrieved October 29, 2020, from https://www.oregon.gov/energy/energy-oregon/Pages/Electricity-Mix-in-Oregon.aspx

Energy Trust of Oregon Inc. (2019, December 16). Solar: Net Metering Retrieved October 29, 2020, from https://www.energytrust.org/solar-net-metering/

Energy. (n.d.). Fossil. Retrieved April 09, 2021, from https://www.energy.gov/science-innovation/energy-sources/fossil

EnergySage. (n.d.). Net Metering for Home Solar Panels. Retrieved October 29, 2020, from https://www.energysage.com/solar/101/net-metering-for-home-solar-panels/

EPA. (2020, September 08). Overview of Greenhouse Gases. Retrieved April 09, 2021, from https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Eschner, K. (2017, March 17). The World's First Solar-Powered Satellite is Still Up There After 59 Years. Retrieved October 24, 2020, from https://www.smithsonianmag.com/smart-news/worlds-first-solar-powered-satellite-still-there-after-59-years-180962510/

Fessler, D. C. (2019). *The energy disruption triangle: Three sectors that will change how we generate, use, and store energy*. Hoboken (New Jersey): Wiley.

Floyd, M. (2019, January 31). Climate report: Warming taking its toll on Oregon. Retrieved September 16, 2020, from https://today.oregonstate.edu/news/climate-report-warming-taking-its-toll-oregon

Fonash, R. (n.d.). Solar Cell. Retrieved April 10, 2021, from https://www.britannica.com/technology/solar-cell

Google. (n.d.) Intel's Ronler Acres Campus. Retrieved October 31, 2020 from https://www.google.com/maps/place/Ronler+Acres+3,+Hillsboro,+OR+97124/@45.54382,-122.9208202,1731m/data=!3m1!1e3!4m5!3m4!1s0x54950578960fbc91:0xe26a24e59decf24f!8m2!3d45.5420589!4d-122.9146981?hl=en

Hanania, J., Stenhouse, K., & Donev, J. (2015, August 26). Photovoltaic Effect. Retrieved October 31, 2020, from https://energyeducation.ca/encyclopedia/Photovoltaic_effect

Helman, C. (2015, February 17). How Much Electricity Do Your Gadgets Really Use? Retrieved October 30, 2020, from https://www.forbes.com/sites/christopherhelman/2013/09/07/how-much-energy-does-your-iphone-and-other-devices-use-and-what-to-do-about-it/?sh=380d68512f70

Helmenstine, A. (2020, August 31). What is an electron? Retrieved April 09, 2021, from https://sciencenotes.org/what-is-an-electron/

Hong, B., & Slatick, E. (1994, August). Carbon Dioxide Emission Factors for Coal. Retrieved October 29, 2020, from https://www.eia.gov/coal/production/quarterly/co2_article/co2.html

Höök, Mikael, and Tang, Xu. "Depletion of Fossil Fuels and Anthropogenic Climate Change—A Review." *Energy Policy* 52 (2013): 797-809. Web

Intel Corporation. (n.d.). Intel Campus Locations in the United States. Retrieved November 01, 2020, from https://www.intel.com/content/www/us/en/location/usa.html

Intel Corporation. (n.d.). Intel: Ronler Acres Campus Retrieved October 31, 2020, from https://www.exploreintel.com/ronleracres?v=7b57966

Jeppesen, M. (2018, March 28). Solar power in space: 60th anniversary of Vanguard 1. Retrieved October 24, 2020, from https://reneweconomy.com.au/solar-power-in-space-60th-anniversary-of-vanguard-1-41568/

Jones, A. (2018, September 3). What exactly is a photon? Retrieved April 10, 2021, from https://www.thoughtco.com/what-is-a-photon-definition-and-properties-2699039

Jones, Geoffrey, and Loubna Bouamane. (2012) "'Power from Sunshine': A Business History of Solar Energy." Harvard Business School Working Paper, No. 12–105

Lindsey, R. (2020, August 14). Climate Change: Atmospheric Carbon Dioxide: NOAA Climate.gov. Retrieved October 29, 2020, from https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Marsh, J. (2019, January 19). What Is Solar Energy? Solar Power Explained: EnergySage. Retrieved October 29, 2020, from https://news.energysage.com/what-is-solar-energy/

NAE Grand Challenge for Engineering. (2019). Retrieved September 15, 2020 from http://www.engineeringchallenges.org/9136.aspx

NAE Grand Challenge for Engineering. (n.d.). Develop Carbon Sequestration Methods. Retrieved October 30, 2020, from http://www.engineeringchallenges.org/9077.aspx

NASA. (2020, August 18). The Causes of Climate Change. Retrieved October 30, 2020, from https://climate.nasa.gov/causes/

NASA. (2021, February 19). Carbon dioxide concentration. Retrieved April 09, 2021, from https://climate.nasa.gov/vital-signs/carbon-dioxide/

Office of Energy Efficiency and Renewable Energy. (2013, August 21). Solar Radiation Basics. Retrieved October 31, 2020, from https://www.energy.gov/eere/solar/articles/solar-radiation-basics

Portland General Electric. (n.d.). Net Metering. Retrieved October 31, 2020, from https://www.portlandgeneral.com/business/power-choices-pricing/renewable-power/install-solar-wind-more/net-metering

Portland General Electric. (n.d.). Sell Power to PGE. Retrieved October 31, 2020, from https://www.portlandgeneral.com/business/power-choices-pricing/renewable-power/install-solar-wind-more/sell-power-to-pge

Rexel Corporation. (n.d.). Solar PV Systems: Overview of the Main Components. Retrieved October 31, 2020, from https://thegrid.rexel.com/en-us/knowledge/energy-efficiency/w/wiki/82/solar-pv-systems-overview-of-the-main-components

Sengupta, M., Y. Xie, A. Lopez, A. Habte, G. Maclaurin, and J. Shelby. (2018). "The National Solar Radiation Data Base (NSRDB)." Renewable and Sustainable Energy Reviews 89 (June): 51-60.

Shinn, L. (2018, June 15). Renewable Energy: The Clean Facts. Retrieved October 29, 2020, from https://www.nrdc.org/stories/renewable-energy-clean-facts

Solar Energy Industries Association. (n.d.). Photovoltaics. Retrieved April 10, 2021, from https://www.seia.org/initiatives/photovoltaics

SunPower. (2020, March 6). SunPower® A-Series Commercial 430–450 Panels. Retrieved October 31, 2020, from https://us.sunpower.com/solar-resources/sunpower-series-commercial-430%E2%80%93450-panels

SunPower. (n.d.). Solar Array Definition. Retrieved October 29, 2020, from https://us.sunpower.com/solar-array-definition

Trabalka, J., & United States. Department of Energy. Office of Basic Energy Sciences. Carbon Dioxide Research Division. (1986). Atmospheric carbon dioxide and the global carbon cycle. Washington, D.C.: U.S. Dept. of Energy, Office of Energy Research, Office of Basic Energy Sciences, Carbon Dioxide Research Division.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved October 30, 2020, from https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php

U.S. Energy Information Administration. (2020, February 20). Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA). Retrieved October 31, 2020, from https://www.eia.gov/tools/faqs/faq.php?id=74

U.S. Energy Information Administration. (2020, July). Independent Statistics and Analysis. Retrieved October 24, 2020, from https://www.eia.gov/state/?sid=OR

U.S. Energy Information Administration. (2020, October 9). Independent Statistics and Analysis Retrieved October 29, 2020, from https://www.eia.gov/energyexplained/coal/how-much-coal-is-left.php

Vidyasagar, A. (2018, October 15). What is photosynthesis? Retrieved April 10, 2021, from https://www.livescience.com/51720-photosynthesis.html

WhatIs. (2006, September 07). Kilowatt-hour (kwh). - definition from whatis.com. Retrieved April 09, 2021, from https://whatis.techtarget.com/definition/kilowatt-hour-kWh

Zohuri, B. (2018). Chapter 4 Types of Renewable Energy. In *Hybrid energy systems: Driving reliable renewables sources of energy storage* (pp. 105-133). Cham, Switzerland: Springer.

APPENDIX A

SUNPOWER®

A SERIES

430–450 W Commercial A-Series Panels

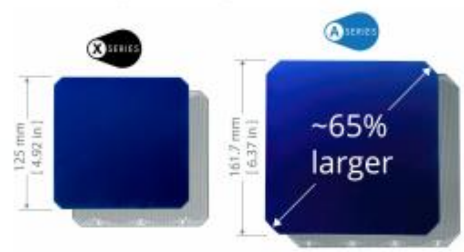
SunPower® Maxeon® Technology

SunPower® Maxeon® cell-based panels maximize energy production and savings by combining industry-leading power, efficiency, and durability with the best power, product, and service warranty in the industry.[1,2]

Reduced Soiling
NEW drainage notch improves performance

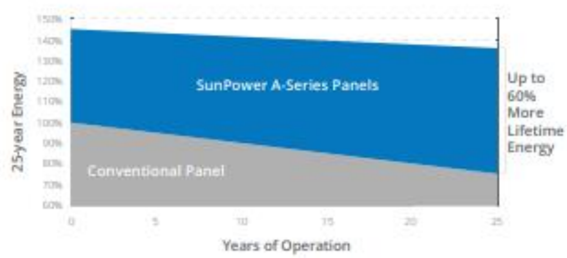
Highest Power Density Available

SunPower's new Maxeon® Gen 5 cell is 65% larger than prior generations, delivering the most powerful cell and highest efficiency panel in commercial solar. The result is more power per square meter than any commercially available solar.[1]



Maximum Lifetime Energy and Savings

Designed to deliver up to 60% more energy from the same space over the first 25 years in real-world conditions like partial shade and high temperatures.[1]



Best Reliability, Best Warranty

SunPower technology is proven to last and we stand behind our panels with the industry's best 25-year Combined Power, Product and Service Warranty.

SUNPOWER MAXEON SOLAR CELL TECHNOLOGY

Fundamentally Different.
And Better.

- Most efficient cell in commercial solar[2]
- Delivers unmatched reliability[4]
- Patented solid metal foundation prevents breakage and corrosion

As sustainable as the energy it produces.

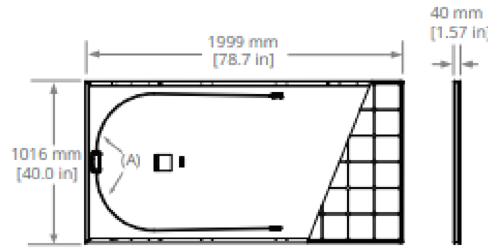
- Achieved the #1 ranking on the Silicon Valley Toxics Coalition's Solar Scorecard for 3 years running
- SunPower modules can contribute to your business's LEED certification[*]

430–450 W Commercial A-Series Panels

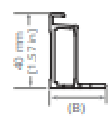
Electrical Data	SPR-A430-COM	SPR-A440-COM	SPR-A450-COM
Nominal Power (Pnom)[5]	430 W	440 W	450 W
Power Tolerance	+5/0%	+5/0%	+5/0%
Panel Efficiency	21.2%	21.7%	22.2%
Rated Voltage (Vmpp)	42.7 V	43.4 V	44.0 V
Rated Current (Impp)	10.1 A	10.2 A	10.2 A
Open-Circuit Voltage (Voc)	51.2 V	51.6 V	51.9 V
Short-Circuit Current (Isc)	10.9 A	10.9 A	11.0 A
Max. System Voltage	1500 V UL		
Maximum Series Fuse	20 A		
Power Temp Coef.	−0.29% / ° C		
Voltage Temp Coef.	−136 mV / ° C		
Current Temp Coef.	5.7 mA / ° C		

Tests And Certifications	
Standard Tests	UL1703
Quality Management Certs	ISO 9001:2015, ISO 14001:2015
EHS Compliance	OHSAS 18001:2007, lead free, Recycle Scheme
Ammonia Test	IEC 62716 (Pending)
Desert Test	MIL-STD-810G (Pending)
Salt Spray Test	IEC 61701 (maximum severity) (Pending)
PID Test	1500 V: IEC 62804
Available Listings	UL, CEC

Operating Condition And Mechanical Data	
Temperature	−40° F to +185° F (−40° C to +85° C)
Impact Resistance	1 inch (25 mm) diameter hail at 52 mph (23 m/s)
Appearance	Class A
Solar Cells	72 Monocrystalline IBC cells
Tempered Glass	High-transmission tempered anti-reflective
Junction Box	IP-68, TE (PV4S)
Weight	47.7 lbs (21.6 kg)
Max. Load	Wind: 75 psf, 3500 Pa, 357 kg/m² front & back Snow: 125 psf, 6000 Pa, 612 kg/m² front
Frame	Class 2 silver anodized



FRAME PROFILE



(A) Cable Length: 1320 mm +/-10 mm [52 in +/-0.4 in]
(B) Long Side: 32 mm [1.3 in]
Short Side: 24 mm [0.9 in]

Please read the safety and installation guide.

1 SunPower 450 W, 22.2% efficient, compared to a Conventional Panel on same-sized arrays (310 W, 16% efficient, approx. 2.0 m²), 4.9% more energy per watt (based on PVSyst pan files for avg US climate), 0.5%/yr slower degradation rate (Jordan, et. al. "Robust PV Degradation Methodology and Application." PVSC 2018).
2 Based on search of datasheet values from websites of top 20 manufacturers per IHS, as of January 2019.
3 #1 rank in "Fraunhofer PV Durability Initiative for Solar Modules: Part 3". PVTech Power Magazine, 2015. Campeau, Z. et al. "SunPower Module Degradation Rate," SunPower white paper, 2013.
4 A-Series panels additionally contribute to LEED Materials and Resources credit categories.
5 Standard Test Conditions (1000 W/m² irradiance, AM 1.5, 25° C). NREL calibration Standard: SOMS current, LACCS FF and Voltage.

See www.sunpower.com/company for more reference information.
For more details, see extended datasheet: www.sunpower.com/solar-resources.
Specifications included in this datasheet are subject to change without notice.

SUNPOWER®