SOLAR ELECTRIC SUPPLY CHAIN DISRUPTION

BY

ELIAS GONZALEZ GOMEZ

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ABSTRACT

This research project focuses on solar electric supply chain disruption and examines the case of Continental Energy, a company specialized in the management and installation of solar PV panels. The project aims to identify and address key challenges within the supply chain to ensure smooth operations, efficient delivery of PV panels, and customer satisfaction. Through a comprehensive analysis of the supply chain network, inventory management techniques, and the implementation of appropriate supply contracts, the project proposes solutions to optimize processes and mitigate disruptions. Furthermore, the economic and environmental impacts of these proposed solutions are evaluated, considering factors such as cost savings, energy efficiency, and sustainability. The project concludes with a comprehensive assessment of the improvements implemented and their potential benefits for Continental Energy's solar electric supply chain. The findings contribute to the understanding of supply chain management strategies in the renewable energy sector and provide insights for companies aiming to enhance their operational efficiency and sustainability in a rapidly evolving industry.

CHAPTER 1

INTRODUCTION

Solar energy is one of the [1]fastest-growing sources of renewable energy, with the potential to power millions of homes and businesses around the world. The solar electric supply chain is complex and can be easily [2]disrupted and can incur to delays, increased costs, and reduced availability of solar products. Currently, the solar electric supply chain is facing several challenges, including supply chain bottlenecks, raw material shortages, and transportation disruptions. These challenges can impact the delivery of solar projects and lead to increased costs, delays, and lost opportunities for businesses and consumers.

The impact of disruption in the solar electric supply chain can be far-reaching, affecting not just the renewable energy sector but also the wider economy. A disrupted supply chain can lead to a reduction in the number of jobs, decreased economic growth, and an increase in carbon emissions as businesses turn to less sustainable sources of energy. However, many experts on the topic are striving to find solutions to these issues. Technological innovations such as blockchain, digital twins, supply chain management and artificial intelligence can be used to mitigate the impact of supply chain disruptions. These solutions can help to increase visibility and traceability in the supply chain, reduce waste, and improve efficiency.

One example of a recent case of solar electric supply chain disruption could be Tesla. Tesla has been expanding its solar energy business in recent years, with a focus on residential solar panels and energy storage products. However, in 2021, the company [3]faced challenges with the supply chain for these products. Tesla's CEO Elon Musk tweeted that the company was "supply-constrained on battery cells and other parts," and that it was "difficult to predict" when the supply chain issues would be resolved. These supply chain issues have resulted in delays in the delivery and installation of Tesla's solar panels and energy storage products. In some cases, customers have had to wait for several months to receive their orders. The company has also had to adjust its pricing and sales strategy in response to the supply chain challenges.

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[1] World Economic Forum, Energy transition: These are the key factors driving the growth of renewable energy. article (6th October 2021). Retrieved from Which factors accelerate the growth of renewable energy? | World Economic Forum (weforum.org)

[2] World Economic Forum, Supply Chains: Why are supply chains facing disruptions, and how long will they last?, article (5th July 2022). Retrieved from Global supply chains face the worst disruptions in decades | World Economic Forum (weforum.org)

[3] Insider: Elon Musk says pandemic supply-chain issues and a global microchip shortage resulted in insane difficulties for Tesla article (26th April 2021). Retrieved from Elon Musk Says Shortages Caused 'Insane Difficulties' for Tesla (businessinsider.com)

Another [4]example of a company that recently experienced supply chain issues related to solar electric is SunPower. SunPower Corporation is a leading manufacturer of solar panels and energy storage systems. In 2020, the company faced supply chain disruptions due to the COVID-19 pandemic. The company's factories in Malaysia and the Philippines had to be temporarily shut down due to lockdown measures, which disrupted its supply chain and resulted in delays in the delivery of its products. SunPower Corporation also faced challenges with its supply chain for solar cells, a key component of solar panels. The company had to increase its reliance on third-party suppliers due to disruptions in its own production facilities. These supply chain challenges had a significant impact on the company's financial performance, with SunPower reporting a loss in Q2 2020.

In conclusion, it seems clear that the solar electric supply chain is facing significant challenges that require innovative solutions. By leveraging technology and collaborating with industry partners, we can ensure a stable and reliable supply chain that supports the growth of the renewable energy sector and the wider economy.

1.1 DESCRIPTION

The purpose of this project is to examine the primary causes of disruptions in the solar electric supply chain and identify potential solutions to overcome them. Specifically, the project will focus on the common challenges in the solar electric supply chain industry, such as supply chain bottlenecks, raw material shortages, and transportation disruptions, and analyze their impact on project timelines, costs, and availability of solar products.

After conducting an initial analysis of the background, the project will be applied to a practical case to assess the real effects of these issues and gather data from the industry. The goal is to study the processes, procedures, and challenges faced by one company, as well as its related providers and stakeholders, and offer solutions from a supply chain perspective to improve their efficiency and effectiveness in receiving and managing solar electric panels. The selected business is Continental Electric Construction Company, which is an EPC (Engineering, Procurement & Construction) company dedicated to design, build, and do the commissioning of solar PV panels

[4] Seeking alpha: SunPower: Supply chain issues are temporary, growth is strong, article (27th December 2021). Retrieved from SunPower: Supply Chain Issues Are Temporary, Growth Is Strong (SPWR) | Seeking Alpha

and energy storage solutions. To conclude, once the best solution for the company is defined, the project will evaluate its economic and environmental impact.

1.2 OBJECTIVES

Objectives are essential to any project because they provide a clear and specific task that the manager can work towards. Without objectives, a project can become unfocused and lack direction, which can result in wasted time and resources.

Having clear objectives for a [5]project helps to:

1. Define the scope: Objectives help to determine the boundaries of a project, by clarifying what is included and what is not included in the project.
2. Prioritize tasks: Objectives help to identify the most important tasks that need to be completed, which can help to prioritize the project work and ensure that the most critical tasks are completed first.
3. Measure success: Objectives provide a standard against which to measure the success of the project. This helps to ensure that the project team is working towards a specific outcome, and that progress can be tracked and reported.
4. Motivate the team: Objectives can provide a sense of purpose and direction for the project team, which can help to motivate them to work towards a common goal.

In summary, objectives are a fundamental aspect of any project because they provide a clear focus and direction for the project team. They help to ensure that the project work is completed efficiently and effectively, and that the project delivers the intended results.

For the solar electric supply chain disruption project, I have decided to apply the SMART goals methodology. [6] SMART is a methodology for setting goals that are Specific, Measurable, Achievable, Relevant, and Time-bound. Using the SMART methodology can help to ensure that goals are well-defined, achievable, and aligned with the overall vision and objectives of the project or organization. It also helps to track progress and ensure that goals are achieved in a timely and

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[5] Jennifer Bridges. Project Manager: How to write effective project objectives every time. article (17th June 2022). Retrieved from How to Write Effective Project Objectives Every Time - ProjectManager

[6] Anna Talerico. Corporate Finance Institute: SMART goals, article (4th March 2023). Retrieved from SMART Goal - Definition, Guide, and Importance of Goal Setting (corporatefinanceinstitute.com)

effective manner. Regarding the project, the SMART goals have been defined considering the following parameters:

S – Specific: The objective is to make the solar PV panels supply chain more efficient in terms of time and money. In this sense, the objectives of the project will be reducing the solar PV panels Lead Time and cutting up spending in the overall PV panel supply chain system. Lead time in industry refers to the amount of time it takes for a product to move through the production process, from the time it is ordered until it is delivered to the customer. It includes all the stages of production, such as ordering raw materials, processing the product, assembling, and packaging it, and shipping it to the customer. Lead time is an important metric for manufacturers, distributors, and other businesses because it affects the ability to deliver products on time and meet customer demand. A shorter lead time can help businesses be more responsive to customer needs, reduce inventory and storage costs, and increase customer satisfaction.

For this case, the lead time considered will include the time from when the panels are ordered by Continental Electric until they are delivered to the work area to be installed. Regarding the economic objectives, the goal is to achieve savings in the overall supply chain, taking into consideration improvements in logistics, transportation, efficiency in operations or even sales rebates when purchasing raw materials.

M – Measurable: it is essential for any project to have metrics that allow the manager to know if the project is on the right path to achieve the objectives, and at the end, evaluate if it has been successful. In most of the projects, sometimes the objective is to improve certain processes or reduce the required time to perform an operation, but will we consider the project successful if we are able to reduce the time or improve the process by 5%? Would it be successful as well if we obtained improvements of 1% instead? That’s why the need for measurable objectives is required. For the current case, the objective is to reduce the overall supply chain spendings by at least 20%. Regarding the lead times, the target is to reduce the PV panels’ lead time by at least a 1%.

A – Achievable: we need to ensure that the metrics and objectives that we want to achieve are somehow attainable, but not too easy for us to accomplish. In this scenario, and always considering the data and the feedback provided by the company, we have decided to establish an objective of 1% reduction in the PV panels' lead time and 20% savings in the budget.

R – Relevant: the objective to achieve must be relevant for the company, which means that needs to improve or add value to the services or goods the company is providing to their customers. In this case, the reduction of the lead times of the panels will ensure the clients can be served earlier and the company will benefit from that. Regarding the economic target, it is always important for companies to keep competitive and try to avoid costs when possible, looking for continuous improvement.

T – Time-bound: as mentioned before, the goals of the project must be accomplished within a certain period. It is not the same to improve a certain operation's efficiency by 5% in one month than doing it in one year. That's why we need to limit the objectives within time. For the current case, as the special project has a specific beginning date and an end date as well, we will consider the objectives to be accomplished for the duration of the special project, which is 6 months, starting from January 15 and ending July 15.

1.3 SCOPE

Before getting deeper into the project, it is also necessary to explain its scope, which basically specifies and includes the boundaries of the topics expected to be covered. An alternative way to define it could be an agreed upon understanding as to what is included or excluded from a project, ensuring that everything is clearly defined and mapped out. A few factors must be considered:

- The business that will be analyzed is known as Continental Electric Construction Company. Inside this big group, there is a smaller branch that is called Continental Energy Solutions, which is the specific department that will be studied and improved.
- It must be considered that inside this function they run many different businesses. As explained previously, they also manage energy storage projects, among others, so it is important to underline that the improvements will only affect the side of solar PV panels.

- The business works with a wide range of PV panels, so the aim of the project will be focused on reducing the computed average lead time and economic expenses coming from the most common ones.

Once the boundaries have been defined, it is typical in engineering projects to include within the [7]scope the following data: the resources, the timeline, and the expected budget:

- **Resources:** As the main sources to perform the research we will use: the 1) Main web of the company, 2) Information available from the Internet, and 3) Interviews with some employees from the company from whom the main real industry data will be extracted.
- **Timeline**: As explained in the final paragraphs of the objectives section, the project is expected to be developed from January 1st to July 1st. In the following table you can see the summarized steps that need to be accomplished to meet the established deadline:

Table 1. Timeline of the project.

Research Activity	Duration	Start	Finish
Prepare Outline of the project	25 h	15 Jan 23	6 Feb 23
Research and planning. Make corrections of outline	20 h	6 Feb 23	15 Feb 23
Search for information on the industry	60 h	15 Feb 23	5 Mar 23
Solar electric disruptors research	40 h	5 Mar 23	15 Mar 23
Search for info on Continental Electric	20 h	15 Mar 23	30 Mar 23
Interview staff from Continental Electric	25 h	1 Apr 23	15 Apr 23
Analyze supply chain of Continental Electric	40 h	15 Apr 23	30 Apr 23
Propose solutions for these issues found on Continental SC and suppliers	80 h	30 Apr 23	30 May 23
Impact of the improvements	40 h	1 Jun 23	10 Jun 23
Prepare list of references & appendices	10 h	10 Jun 23	20 Jun 23
Review	20 h	20 Jun 23	25 Jun 23

[7] Coursera: Google Project Management Professional Certificate- Project initiation, teaching content. Retrieved from Google Project Management: Professional Certificate | Coursera

Various meeting along the project	50 h	1 Jan 22	20 Jul 23
Draft ultimate corrections	10 h	25 Jun 23	20 Jul 23
Prepare final presentation	10 h	20 Jul 23	25 Jul 23

- **Budget**: In this case, similarly to other engineering projects we also need to compute the expected budget for the project. There are two different perspectives to analyze it:
  1) In terms of time: the total amount of time that is going to be invested in the project is related to the data of the timeline provided before. The time invested is equal to 540 hours, which is the minimum time required by the faculty staff.
  2) In terms of money: It should be considered the 6 credit hours of the project multiplied by its average credit hour price of [8]$1,712, which gives us a total budget of $10,272.

  Operating on both terms, the average price per project hour can be computed: **$19.03/hour**.

[8] Illinois Institute of Technology: Admission and Aid, Graduate Costs and Aid. Retrieved from: Graduate Costs and Aid | Illinois Institute of Technology (iit.edu)

CHAPTER 2

CHALLENGES OF SOLAR ELECTRIC SUPPLY CHAIN

The purpose of this new chapter is to provide some insight into the principles of solar energy and the solar energy industry to gain some knowledge on how solar panels work and their manufacturing processes. Specifically, the background of the solar energy will be explained, covering the energy conversion processes, incoming solar panels' radiation and the different types of solar power plants available in the market. After this general context, the focus will be on the study of the solar PV panels, which is the core technology used in Continental Electric and the supply chain that wants to be analyzed in this project. The basic understanding of these concepts will allow later in this chapter to link the supply chain concept to the solar PV manufacturing industry and find out the main supply chain disruptors.

2.1 STATE OF THE ART

Solar energy has emerged as a promising source of renewable energy due to its sustainability and its potential to reduce dependence on fossil fuels. At the core of solar energy are solar panels, which capture sunlight and convert it into electricity. Solar panels consist of several key parts, including photovoltaic cells, a frame, a glass cover, and wiring. These parts work together to generate electricity from the sun's energy. The manufacturing process of solar panels involves several stages, including the production of raw materials, wafer and cell production, module assembly, and testing. In this section, we will explore the workings of solar panels, the key components that make up solar panels, and the manufacturing process involved in their production.

2.1.1 Background of solar energy

Solar energy

Solar energy is a renewable energy source that uses the radiant heat and light coming from the sun to convert it into useful energy. The main reason why it is considered renewable is because it is derived from the sun, which is a virtually infinite source of energy. Unlike fossil fuels, which are finite and will eventually be depleted, solar energy is constantly being replenished. The sun's energy is expected to last for billions of years, meaning that solar power will remain a viable source of energy for the foreseeable future. Moreover, solar energy is considered a clean and sustainable source of energy, as it does not produce harmful emissions or pollutants that can damage the environment or contribute to climate change.

Radiation phenomena

As it is known, not all the beams coming from the sun in the form of irradiation (if talking about power) or irradiance (if talking about the energy) can be used by solar panels to produce energy. There is a significant part of them that are lost due to the [9] **reflection**, **conduction,** and the **absorption** of the beam when impacting against the **ozone layer**:

- **Reflection**: When a beam of sunlight hits the ozone layer, some of the light may be reflected back towards space. This happens when the angle of incidence is such that the light is reflected off the ozone layer without penetrating it. This is similar to how light reflects off a mirror or other reflective surface.
- **Absorption:** When a beam of sunlight hits the ozone layer, some of the light may be absorbed by the ozone molecules. This absorption causes the molecules to become excited and move to a higher energy state. This energy can be released as heat or light, which can further interact with other molecules in the atmosphere.
- **Conduction**: When a beam of sunlight hits the ozone layer, some of the energy from the light may be conducted through the layer and into the atmosphere. This can cause the surrounding air to become warmer, which can affect atmospheric processes such as convection and turbulence.

It's important to note that these three scenarios can occur simultaneously and are not mutually exclusive. The exact proportions of reflection, absorption, and conduction will depend on various factors such as the angle of incidence, the wavelength of the light, and the properties of the ozone layer and surrounding atmosphere. This percentage of beams that can successfully penetrate the ozone layer and get into the atmosphere are commonly known as Ultraviolet Radiation (UV radiation) and are the ones with shorter wavelengths than the visible light.

Solar power plants radiation

[9] Francesc Guinjoan, Electronic Engineering Department – Universitat Politecnica Catalunya: Solar Energy PV, Renewable Energy Course, essay.

This former radiation is now susceptible to being used by solar power plants. They will receive different kinds of [10]beams arriving towards the panels' surface:

- **Direct radiation:** it is the radiation from the sun that passes in a straight line through the atmosphere to the receiver.
- **Diffused radiation:** it is supposed to be the solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or particles in the atmosphere. Clouds strongly increase this component.
- **Reflected radiation:** it is also known as **Albedo radiation**, is the sum of the direct and diffuse radiation that is reflected by the Earth's surface towards the receiver.

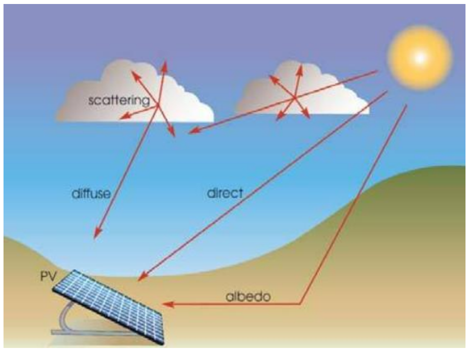

Figure 1. Radiation in solar panels. (Source: ResearchGate.net).

<u>Solar power plants technologies</u>

Nowadays, there are 3 main types of solar equipment available in the market that have been classified depending on their technology, applications, and characteristics: solar thermal, solar thermodynamic and solar photovoltaic (PV):

- **Solar thermal plants** use mirrors or lenses to concentrate sunlight onto a small area, creating intense heat that can be used to generate electricity. The heat is used to produce steam, which drives a turbine to generate electricity. Solar thermal plants are typically large-scale power plants that require a large amount of space and high levels of sunlight. They are well-suited for areas with high levels of direct sunlight, such as deserts, and are often used in utility-scale applications to generate large amounts of electricity.

[10] Francesc Guinjoan, Electronic Engineering Department – Universitat Politecnica Catalunya: Solar Energy PV, Renewable Energy Course, essay.

- **Solar thermodynamic plants** are similar to solar thermal plants, but they use a different process to generate electricity. They use a heat transfer fluid (such as molten salt or special types of oils) to transfer heat from the sun to a power block, which then generates electricity using a steam turbine. Solar thermodynamic plants are typically smaller and more flexible than solar thermal plants, making them well-suited for smaller-scale applications. Among its main uses, it stands out generating heat for a solar domestic heat water or solar pool heating systems.
- **Solar photovoltaic** plants use photovoltaic cells to convert sunlight directly into electricity. These cells are made from semiconductor materials such as silicon and are typically arranged in modules to form a solar panel. When sunlight hits the PV cells, it creates an electric field that allows electrons to flow and generate electricity. Solar PV plants are typically smaller and more flexible than solar thermal or solar thermodynamic plants and can be installed on rooftops, in large-scale solar farms, or as portable solar devices such as solar-powered chargers.

The main differences between these three types of solar power plants are the technology they use to generate electricity, their size and scalability, and their applications. Solar thermal and thermodynamic plants are typically larger and more suited for utility-scale applications, while solar PV plants are smaller and more suited for distributed energy applications. Additionally, solar thermal and thermodynamic plants are typically better suited for areas with high levels of direct sunlight, while solar PV plants can operate in a wider range of conditions. Finally, solar thermal and thermodynamic plants use heat to generate electricity, while solar PV plants directly convert sunlight into electricity. Some examples of these kind of solar power plants can be found in the following paragraphs:

  - Concentrated solar power (CSP) - This technology uses mirrors or lenses to concentrate sunlight onto a small area, creating intense heat that can be used to generate electricity. The heat is used to produce steam, which drives a turbine to generate electricity.

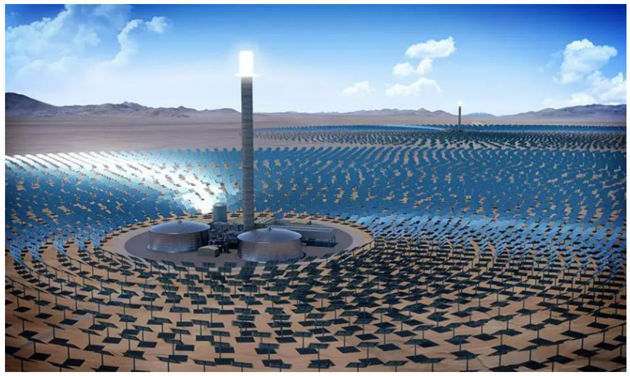

Figure 2. Example of CSP with a central tower. (Source: ResearchGate.net).

- Flat plate collectors - These collectors are typically used for residential hot water systems. They consist of a flat, insulated box with a dark-colored absorber plate inside. When sunlight hits the plate, it heats up and transfers the heat to a fluid flowing through pipes in the box.

Figure 3. Example of flat plate collector. (Source: Innergy.com)

- Evacuated tube collectors - These are similar to flat plate collectors, but they use a series of glass tubes to reduce heat loss and improve efficiency.

Figure 4. Example of evacuated tube collectors. (Source: Innergy.com)

- Solar air heating - This technology uses air as the heat transfer medium, typically in a space heating system. The air is heated by sunlight passing through a collector, and then circulated through the building using fans or ducts.

Figure 5. Example of solar air heater system. (Source: Innergy.com).

2.1.2 Solar PV Panels

After having reviewed the principles of solar energy and understood the main types of solar power plants, it is now time to focus on the specific technology that Continental Electric manages daily. The aim of this section is to describe the main parts that compound solar photovoltaic panels (also known as PV panels) and gain some knowledge about the basic operation concepts and standards.

PV Conversion chain

A solar PV panel is a device that converts sunlight into electricity. It is made up of solar cells, which are semiconductor devices that absorb photons from the sun and release electrons, creating an electric current. Contrary to a solar thermal panel, which intention is to reflect the light and concentrate the heat into a specific point, a PV panel goal is to produce energy by means of the photovoltaic effect. The basic structure of a PV solar panel consists of several layers of different materials. The top layer is made of a transparent material, such as glass or plastic, that allows sunlight to pass through. The next layer is the PV layer, which is made up of several individual solar cells. Each solar cell consists of two layers of silicon that have been doped with different impurities to create a p-n junction. This junction creates an electric field that separates the electrons and holes, allowing them to flow in opposite directions and generate a current.

The current generated by each solar cell is typically small, so multiple cells are connected to form a module, and multiple modules are connected in series and parallel to form a PV array or PV generator. With this generated power, PV arrays can supply different loads:

- Electrical loads
- To charge batteries
- Inject energy to the main grid.

PV systems classification

PV solar panels are commonly used in residential, commercial, and utility-scale applications to generate clean, renewable energy from the sun. They are a popular option for those looking to reduce their carbon footprint and save money on energy bills over the long term. Depending on their applications and connection system with the grid, they can be classified as follows:

- **Off-grid PV systems**: not connected to the mains, used for stand-alone applications. They should use batteries.
- **Grid-connected systems**: The system is connected to the grid and can inject or extract power from the mains.

- **Hybrid systems**: In these cases, at least an additional power source is present (wind, diesel, …). Can be off-grid or grid-connected.

2.1.3 PV Panels manufacturing's process

After reviewing the different available solar technologies and understanding the basics of solar PV panels it is time to focus on their manufacturing processes. The purpose of this section is to learn about the various manufacturing stages of a solar PV panel and try to evaluate later the impact of these into the supply chain of Continental Electric.

The [11] PV manufacturing processes involves several complex stages that require specialized equipment, skilled labor, and precision engineering. The main stages of the PV panel manufacturing process involve:

- **Silicon production**: The first step in producing PV panels is to create high-purity silicon, a process that is expensive, energy-intensive, and produces significant greenhouse gas emissions. This process involves heating and melting raw silicon with other materials to create a purified silicon ingot. To manufacture the fine-grained crystalline silicon product called polysilicon, methods relying on highly reactive gases, such as hydrogen and chlorine, are used. The Siemens process and the floating bead method are two commonly used methods for producing polysilicon. In the Siemens process, a silicon-hydrogen-chlorine compound gas passes over a heated silicon filament, breaking the molecular bonds and depositing the silicon atom on the filament, which ultimately grows into a large U-shaped polysilicon rod. The filament itself is also made of pure silicon to avoid contamination. In the floating bead method, small silicon beads sit at the bottom of an inverted cone-shaped vessel where a compound gas of silicon and hydrogen is pumped in, causing the small beads to float near the surface. The heating of the vessel breaks the silicon-hydrogen bonds, causing the silicon atoms to deposit onto the small beads until they become too heavy to float and drop to the bottom of the vessel where they are harvested, ready for use.
- **Wafer production**: In the next stage of PV panel manufacturing, the purified silicon ingot is sliced into thin wafers using a diamond wire saw or other methods. However,

[11] Solar Energy Technologies Office: Solar photovoltaic manufacturing basics, website. Retrieved from Solar Photovoltaic Manufacturing Basics | Department of Energy

this process can be costly and result in a high degree of material loss. The diamond wire saws used in the wafer production process can be expensive to acquire and maintain, and the cutting process can result in a high degree of material loss, reducing the overall efficiency and profitability of the process. Another method involves turning polysilicon into wafers by heating it until it forms a liquid mass, then growing a large cylindrical ingot of monocrystalline silicon in the Czochralski process or forming a large-grained multicrystalline-silicon ingot in the directional solidification process. After that, silicon ingots are sliced into very thin wafers using diamond-coated wire saws. The silicon sawdust created in the process is called kerf. While kerfless wafer production can be achieved by pulling cooled layers off a molten bath of silicon or by depositing a thin layer of silicon atoms onto a crystalline template using gaseous silicon compounds.

- **Cell production**: The wafer is then coated with a thin layer of phosphorus to create a positive charge on one side and a negative charge on the other. The wafer is then baked to create a permanent electrical field. The difficulties associated with this stage are primarily related to the quality control and consistency of the process. Defects in the silicon or cell production process can lead to reduced efficiency or even complete failure of the panel, which can result in significant losses for manufacturers.
- **Module assembly**: After the silicon wafers have been produced, they are arranged in a specific pattern and sealed between two sheets of glass or plastic to create a PV panel. The panels are then wired together to create an array capable of producing usable electricity. At a module assembly facility, copper ribbons plated with solder connect the silver busbars on the front surface of one cell to the rear surface of an adjacent cell in a process known as tabbing and stringing. The interconnected set of cells is arranged face-down on a sheet of glass covered with a sheet of polymer encapsulant. A second sheet of encapsulant is placed on top of the face-down cells, followed by a tough polymer backsheet or another piece of glass. The whole stack of materials is laminated in an oven to make the module waterproof, then fitted with an aluminum frame, edge sealant, and a junction box in which the ribbons are connected to diodes that prevent any backward flow of electricity. The difficulties associated with this stage are

primarily related to the cost, quality control, and skilled labor required for the manufacturing process. The materials used to create the PV panel can be expensive, and defects in the manufacturing process can lead to reduced efficiency or complete failure of the panel, resulting in significant losses for manufacturers. Additionally, specialized equipment and skilled labor are necessary to ensure high-quality control during the manufacturing process.

Figure 6. Stages of PV panels processing. (Source: Dawtec.com).

The mounting and commissioning processes that follow the production of solar panels will not be discussed in this project as they are beyond its scope, as was explained at the beginning of the project. The project will only analyze the lead times from when the panels are ordered to when they are delivered and ready to be installed, excluding the installation processes of mounting and commissioning.

As has been explained, the different manufacturing stages need to be done within strict limits and tolerance, high amounts of resources (energy, temperature, …) and with limited and high-priced materials. These factors added to the inner complexity of the processes enhance the possibility of supply chain disruptions within the solar electric industry.

2.2 MAIN SUPPLY CHAIN DISRUPTORS

After having reviewed solar electric PV panels main characteristics and explored the manufacturing process involved in their production it is now time to link these concepts to the core of the project: the supply chain disruptors of the PV panels from Continental Electric. To do that, some insight into the supply chain basic concepts will be provided in this section, as well as the existing disruptors that may arise in any supply chain.

2.2.1 Supply chain

A supply chain is a network between a company and its suppliers to produce and distribute a specific product, and it represents the steps it takes to get the product or service to the customer. The traditional supply chain network usually involves the same entities within its product or service flow towards the end user: suppliers, manufacturers, warehouses, distribution centers, outsourcing companies, third-party logistic companies, and customers. The primarily objectives of a supply chain are:

- To **maximize customer satisfaction** by providing high-quality products or services that meet their needs and expectations.
- To **minimize the total cost of the supply chain** by optimizing the use of resources and minimizing waste.
- To **improve the efficiency and effectiveness of the supply chain** by reducing lead times, increasing productivity, and enhancing collaboration between different entities in the supply chain. It is important to underline the difference between efficiency and effectiveness: while efficiency means doing something at the lowest possible cost, effectiveness means doing the right things to create the most value.

Overall, it can be stated that the goal of a supply chain is to manage the flow of goods, services, and information efficiently and effectively from the point of origin to the point of consumption, while minimizing costs and maximizing the overall customer value. To succeed and achieve these objectives, several techniques have been developed during the last years. It all started with Traditional Mass Manufacturing in the 1950's and has evolved to what we know now as **Supply Chain Management**, passing through Just In Time, Total Quality Management or Cost Optimization techniques.

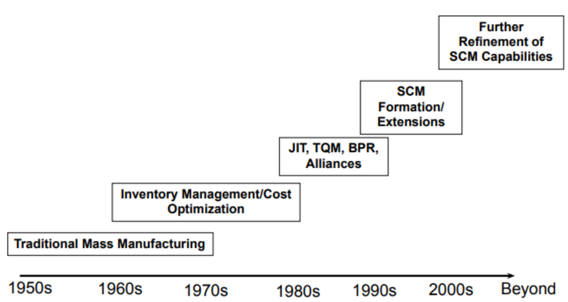

Figure 7. Evolution of the Supply Chain Techniques.(Source: LeanInstitute.com).

Supply chain management is a set of approaches used to effectively integrate suppliers, manufacturers, warehouses, stores, and consumers, so that merchandise or services are produced and distributed.

- It represents a conscious effort by the supply chain firms to develop and run supply chains in the most effective & efficient ways possible.
- Supply chain activities cover everything from product development, sourcing, production, and logistics, as well as the information systems needed to coordinate these activities. Upstream the supply chain, these activities may reach the raw materials stage. Downstream in the supply chain, these activities may reach the end customer stage.
- Uncertainty and risk are always there, regardless of how good the supply chain strategy is.

As stated on previous chapters, the aim of this project is to analyze the current supply chain of Continental Electric, and the importance of the Supply Chain Management is basic because it would be used as the main tool to overcome the different challenges that the company is currently facing regarding the PV panels' branch of the business.

Supply Chain Management decisions have multiple levels of plans and activities, and can be classified depending on the effect the decisions may have on the business:

- The strategic level deals with decisions that have a long-lasting effect on the firm.
- The tactical level includes decisions that are typically updated anywhere between once every quarter and once every year.
- The operational level refers to day-to-day decisions.

This project will focus on providing Continental Electric with strategic and tactical solutions, not just to ensure that the company will be benefited from the long-lasting effects of these decisions, but also because it would be hard to act on the day-to-day activities of the company. According to[12] David Simchi-Levi and Philip Kaminsky on Designing and Managing the Supply Chain, to be successful, the firms must take actions to:

[12] David Simchi-Levi, Philip Kaminsky & Edith Simchi-Levi. Designing and Managing the Supply Chain 4th edition, essay (2022)

- Match supply chain strategies with product characteristics. For instance, a company that works with electrical components that are currently suffering shortages cannot have the same supplying policies as they had 10 years ago. Another example could be a company that launches a new innovative product that may require different supply needs with respect to the product lines of the business.
- Replace traditional supply chain strategies with those that yield a globally optimized supply chain. This means not just analyzing a single department or function when taking actions; instead of that, mapping out the big picture of the company and taking the actions that would benefit the overall organization.
- Effectively manage uncertainty and risk.

2.2.2 Supply chain disruptors

Supply chain disruptions are events that occur unexpectedly and can impact the flow of goods and services from the manufacturer to the end consumer. These disruptions can cause delays, increase costs, and reduce overall supply chain efficiency. There are several types of supply chain disruptors, including operational, macroeconomic, technological, geographic, and environmental. Each type of disruptor has its own unique characteristics and can affect supply chains in different ways:

Operational Disruptors

[13]Operational disruptors are disruptions that occur within a company's own supply chain operations. These disruptions can include equipment failures, inventory shortages, production delays, and quality issues. Some common [14]examples of operational disruptors include:

- Production disruptions caused by equipment failure or breakdowns. These can cause delays in the production process and result in increased costs.
- Quality issues with raw materials or finished products. These issues can lead to product recalls, reputational damage, and financial losses.

[13] John Westwood. Supply Chain Management World - Supply Chain Disruption: How to Identify, Prevent and Manage It, article.
[14] Mary Shacklett. Tech Republic - 7 Types of Supply Chain Risk: Understanding the Different Types, article.

- Inventory shortages caused by poor planning or unexpected demand spikes. These can lead to stockouts, delays, and lost sales.

Macroeconomic Disruptors

[15] Macroeconomic disruptors are disruptions that occur due to changes in the larger economic environment. These disruptions can include changes in interest rates, inflation, foreign exchange rates, and government policies. Some common [16] examples of macroeconomic disruptors include:

- Economic recessions or downturns. These can cause decreased demand for products and services, leading to excess inventory and reduced sales.
- Changes in currency exchange rates. These can impact the cost of importing/exporting goods and services, potentially resulting in higher costs or reduced profitability.
- Trade policy changes. These can impact the flow of goods and services across borders, potentially leading to increased costs or disruptions in the supply chain.

Technological Disruptors

Technological disruptors are disruptions that occur due to advances in technology. These disruptions can include changes in manufacturing processes, new products, and advancements in transportation and logistics. Some common examples of technological disruptors include:

- Advances in automation and robotics. These can lead to increased efficiency and lower costs in manufacturing and warehousing but can also result in job losses.
- Introduction of new products or services. These can disrupt existing supply chains and create new supply chain opportunities.
- Advancements in transportation and logistics technologies. These can lead to faster and more efficient transportation but can also result in disruptions if companies are not able to adapt quickly enough.

Geographic Disruptors

Geographic disruptors are disruptions that occur due to political instability, or other events that impact specific regions or countries. These disruptions can include port

[15] Supply Chain Digital - The Top 10 Macro Disruptors Supply Chains Need to Watch in 2021, article.
[16] EY – Macroeconomic disruption: Understanding the Risks, article.

closures, transportation disruptions, and supply chain disruptions due to supplier location. Some common examples of geographic disruptors include:

- Political instability or conflict in specific regions. These can impact the ability to transport goods or access certain markets, potentially leading to increased costs or supply chain disruptions.
- Supplier location. If the current suppliers or outsourcing companies are not close enough to the main business, there may be the risk of working under supervision and the processes may get out of control as cannot be monitored directly.

Environmental Disruptors

Environmental disruptors are caused by changes in the natural environment, such as climate change, resource depletion, and pollution. Some examples of environmental disruptors include:

- Climate change: Rising sea levels, changing weather patterns, and increased frequency and severity of natural disasters can disrupt supply chains and impact production and transportation.
- Resource depletion: Depletion of natural resources such as water, oil, and minerals can lead to supply chain disruptions and increased costs.
- Natural disasters such as hurricanes, earthquakes, or floods. These can impact transportation and infrastructure, potentially causing delays and disruptions in the supply chain.
- Pollution: Environmental pollution, including air and water pollution, can impact supply chains by causing health risks, reduced productivity, and increased costs.

CHAPTER 3

PRACTICAL CASE: CONTINENTAL ELECTRIC

The aim of this chapter is to apply all the knowledge and techniques that have been mentioned in the previous chapters in order to face the current supply chain disruptors. The idea is to analyze the case of Continental Electric, gain more insight into the company and their procedures, and identify which kind of disruptors are most common among their daily issues. Once identified, the point is to propose the most optimal and adequate solutions that will allow the company to be more efficient and effective internally, but also towards their main customers.

3.1 PURPOSE OF CONTINENTAL ELECTRIC

Continental Electric Construction Company is a privately held electrical contracting company based in Oak Brook, Illinois, a suburb of Chicago. The company was founded in 1912 and has been providing electrical services to the Chicago area for over a century.

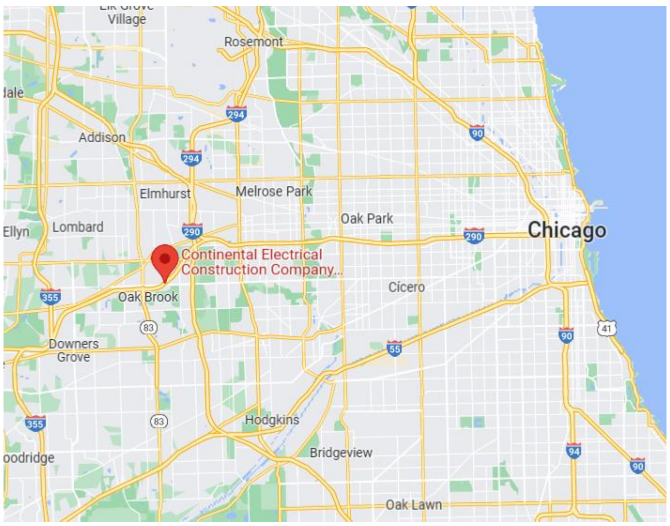

Figure 8. Continental Electric's Headquarters.

The company's core business is electrical construction, including power distribution, lighting systems or fire alarm systems, but they are also running other businesses like data communication systems. They specialize in the construction and renovation of commercial, institutional, and industrial facilities. As for the company's size, [17]according to the main website

[17] Continental Electric Construction Company, official website. Retrieved from [Chicago's Leading Electrical Contractor | CECCo]

of the company, they employ over 500 people. They have a large and experienced team of electricians, engineers, project managers, and support staff to handle a wide range of projects. To manage these various projects the company has been organized as follows:

- Engineering Department: This department is responsible for designing and planning electrical systems, including power distribution, lighting, and communication systems. They also conduct feasibility studies and provide technical support for ongoing projects.
- Estimating Department: The estimating department is responsible for analyzing project plans and specifications and preparing cost estimates for materials, labor, and equipment. They work closely with the engineering department to ensure accurate estimates.
- Project Management Department: This department is responsible for overseeing the planning, execution, and completion of projects. They work closely with the estimating department to ensure projects are completed on time and within budget.
- Purchasing Department: The procurement department is responsible for purchasing and managing the inventory of materials, equipment, and supplies needed for projects. They work closely with the estimating department to ensure that the required materials are available at the right time and at the best prices.
- Field Operations Department: This department is responsible for the installation, testing, and commissioning of electrical systems on site. They work closely with the project management department to ensure that projects are completed according to plan.
- Safety Department: The safety department is responsible for ensuring that all employees and contractors work in a safe and healthy environment. They develop and enforce safety policies and procedures and provide training to employees and contractors.
- Accounting Department: The accounting department is responsible for managing the company's finances, including invoicing, accounts payable, accounts receivable, and financial reporting.

Because of the different functions the company has, and its size, the company decided to create a specific subsidiary company to manage the PV solar projects. Therefore, the focus will be on a specific branch of the business, called **Continental Energy Solutions,** which is the part responsible for the **design, installation and commissioning of solar PV arrays and battery storage solutions**:

- This specific team involves about **60 workers**, including office and field personnel.
- Their **offices are in Oak Brook** as happens with the biggest part of the group, and they also have **one warehouse**. They only store there their main **tools, machinery or special equipment** for the projects.
- Regarding the kinds of project they do, they **only perform grid-connected installations**, which means that all installations are for commercial or industrial clients, not domestic installations.
- The biggest part of the projects is carried out in the northern part of Illinois, Indiana, Ohio, Wisconsin, Virginia and Pennsylvania.
- Regarding their **suppliers and tool providers**, they are mostly located on the **West and East coast of the US**.

3.2 SUPPLY CHAIN ANALYSIS

Once Continental Electric has been introduced into the project, it is time to get deeper into their procedures and learn about the main processes of the company and their supply chain management. The aim of this section is to explain and analyze the challenges the company is facing due to both internal and external inefficiencies in the form of disruptors.

OPERATIONAL DISRUPTORS

This first part will delve into the operational disruptions that are affecting Continental Electric's PV panels supply chain. Operational disruptors were those related to the company's supply chain and are identified as main internal issues such as procedure inefficiencies, equipment failure and quality problems or inventory shortages. Some of the operational disruptors that have been identified within Continental Energy are:

<u>Purchasing procedures</u>

It is a fact that in most current companies, the majority of purchases must be authorized by the company's management before ordering them. It is a control tool that companies use to ensure that employees are following the guidelines provided by high executives and to keep the project's budget on track. However, the case of Continental Electric is extreme and has too many internal stages that need to be done before the approval for the purchase order. Specifically, the purchase request must meet the following criteria:

- Providers or suppliers offers: the purchase request must be submitted with at least 4 more offers from different suppliers, with different paperwork regarding delivery time, total price, shipping price and health and safety regulatory compliance with the company. In some cases, it can be tedious to find more than 5 companies that are able to provide you with the service or goods you are looking for. That's why in various projects, the company has spent more time looking for alternative providers rather than receiving the supplies when the order was purchased.
- Company's compliance: The supplier or provider must be registered on the internal software of the company, which is a process that if hasn't been performed previously for that supplier, may take up to 10 or 15 business days.
- Multiple approvals: Must be approved by the technician who has the need, the purchasing technician, the purchasing manager, the business unit manager, and depending on the amount of money that the purchase requires, may require director's approval as well.

All these intermediate steps that are required before a purchase's approval have ended up causing delays in deliveries, product price rises and customers dissatisfaction as haven't been capable of satisfying their need in time.

Centralized purchasing department

One of the defining characteristics of Continental Electric's purchasing department is that it consists of a centralized functional, which basically means that all purchasing activities for the whole organization are handled by a single department or team. This department is responsible for managing all aspects of procurement, including vendor selection, negotiation, and purchase order management. This type of purchasing department can help streamline processes and increase purchasing power, which can lead to cost savings for the organization. However, having this purchasing commodities instead of a decentralized department in big companies such as Continental Electric has led them to different inefficiencies:

- Delayed decision-making: With centralized purchasing, all decisions must go through a single department or team. This can cause delays in decision-making, especially if there is a high volume of requests.

- Lack of specialized knowledge: With centralized purchasing, the same department is responsible for purchasing across all areas of the organization. This can lead to a lack of specialized knowledge in specific areas, resulting in suboptimal purchasing decisions.
- Resistance to change: Centralized purchasing can be resistant to change, especially if the established processes have been in place for a long time. This can lead to missed opportunities for process improvement or adopting new technologies.
- Bureaucracy: Centralized purchasing can sometimes lead to bureaucracy, with multiple layers of approval and complex procedures. This can slow down the purchasing process and decrease efficiency.

Inventory shortage

Inventory shortage is probably one of the most common types of operational disruptors that affects most companies but also direct consumers. [18]According to recent data, approximately 60% of US citizens have experienced inability to get a certain good or product due to inventory shortage. These kinds of operational disruptions occur when there is not enough inventory to meet demand and satisfy the client’s needs, leading to lost revenue. Inventory shortages can be caused by various factors, including unexpected increases in demand, production delays or other causes.

Continental Electric has identified PV panel shortages, as well as related materials such as batteries, inverters, and cabling systems, as the most significant operational disruptor for the company. In fact, the primary reason why a large portion of their projects have been delivered late to clients is due to the shortage of PV panels. Some of the root causes for these inventory shortage disruptions have been identified:

- Project policies: According to the management guidelines, strategic materials such as PV panels and their related components aren’t supposed to be purchased and therefore, delivered, before the start date of a project, a fact that makes it impossible to buy or reserve any of these materials in advance.
- Warehousing strategies: The company has only 1 warehouse, with the purpose of storing tools and machinery. According to the interviewed personnel, it is too small to store bigger materials like solar panels or related components, so even if the company’s policies will

[18] Lydia Saad. Most US Consumers Have Felt Supply Chain Problems, article (11st August 2021). Retrieved from: Most U.S. Consumers Have Felt Supply Chain Problems (gallup.com)

allow their technicians to purchase these elements in advance and try to avoid potential shortages, the space to store them still wouldn't be enough. Maybe keeping some of these materials with safety stock levels will help to mitigate risks associated with PV shortages.

- Forecasting models: Forecasting is a critical aspect of a company's demand and planning process. It helps to provide insights into the future and allows companies to estimate the resources they will need in the next period. At Continental Electric, however, they did not use any forecasting model to predict the needs for PV panels. Instead, they would communicate with their customers and only try to acquire the necessary materials after closing the contract as quickly as possible. From my point of view, using time series model or mathematical models that identify patterns and consider critical factors such as level, trend and seasonality could be useful to anticipate the purchase of PV panels and avoid key materials shortages. However, some people could argue that it would be impossible to predict what type of panels should be purchased in advance to save some time and reduce lead times because each project may use different PV panels. Luckily for Continental Electric, the PV panels required for their installations are the same in approximately 80% of cases, a fact that would reduce significantly the risk involved in purchasing these kinds of materials in advance. The specific model they usually purchase is a Q-cell based solar PV formed by cells of 156 mm x 156 mm and 200 µm thickness.
- Suppliers' shortage: Continental Electric has frequently faced challenges in initiating projects due to delays in the delivery of purchased materials by suppliers. Despite providing sufficient lead time for procurement and creating the purchase order with enough time, the supply side of the process, including providers and suppliers of Continental Electric, has often encountered issues causing disruptions to project timelines. It is important to remember that PV panels are mainly conformed by semiconductor materials, as was explained in Chapter 2, which [19]current limited availability and accessibility is leading semiconductor technology-based companies to experience supply shortages with no signs of stopping. Obviously, construction companies like Continental Electric that

[19] Falk Meissner. Roland Berger: Semiconductor shortage 2023: A different kind of trouble ahead, article (9th November 2022). Retrieved from: Semiconductor shortage 2023: A different kind of trouble ahead | Roland Berger

depend on semiconductor technology' manufacturers will also experience the effect of their supplier's shortage.

MACROECONOMIC DISRUPTORS

This second part of the supply chain analysis will delve into the macroeconomic disruptions. Just to remember what was stated in Chapter 2, macroeconomic disruptors were those challenges associated with the larger economic environment. These kinds of disruptors will typically include economic recessions, changes in currency exchange rates or other similar macroeconomic events.

Economic recession

The current and foreseen economic recession has been a significant macroeconomic disruptor, affecting businesses and industries across the world. According to [20]recent surveys, within the next years both companies and consumers will be overwhelmed by high inflation rates (past year achieved an historical maximum of 9.1% in June) leading them to slow their spending and investment. For Continental Electric, the challenges associated with the current recession can be significant and far-reaching:

- Financial pressure of suppliers: One of the primary challenges that Continental Electric may face is the disruption of its supply chain due to financial pressures on its suppliers. If suppliers are struggling financially, they may delay or cancel orders, leading to disruptions in the supply chain.
- Suppliers' quality issues: Additionally, suppliers may have to cut corners, leading to lower-quality materials and products, which could have a downstream impact on Continental Electric's operations and reputation.
- Demand fluctuation: Another challenge is the fluctuation in demand for Continental Electric's products and services. With consumers cutting back on spending during a recession, the demand for Continental Electric's products may decline, which could lead to excess inventory and financial pressures on the company. Alternatively, demand may increase for certain products due to changes in consumer behavior during a recession,

[20] Christopher Rugaber. ABC News: How will we know if the US economy is in a recession, article (27th April 2023). Retrieved from: How will we know if the US economy is in a recession? - ABC News (go.com)

which could lead to inventory imbalances and potential stockouts if the company is not prepared to meet the increased demand.

<u>Currency exchange rates</u>

It is known that the currency exchange rate in the US hasn't been the strongest one during the last years if compared to other currencies like the Euro. The currency exchange rate has a vital importance for companies, especially for those that perform international transactions or purchases or simply operate with international customers. Some of the issues associated with this kind of disruptor are the following:

- Increased Import Costs: A weaker US dollar could make imported goods and raw materials more expensive. This can lead to higher input costs for Continental Electric, potentially impacting their profitability and increasing the prices of their products or services.
- Reduced Profit Margins: If the company relies on exports as the key to overcoming a weaker US dollar exchange rate, this could make their products more competitive in international markets with lower currency values. However, if the company's expenses and operations are primarily in US dollars, the lower exchange rate may diminish their profit margins when converting foreign earnings back into US dollars. Luckily, as stated in previous chapters, the main customers of Continental Energy are in the northern part of the state of Illinois and other states such as Ohio or Indiana. Despite not representing specifically a problem for Continental Energy, the overall Continental Electric Construction group that manages international projects may have been affected by this fact.
- Supply Chain Disruptions: Currency fluctuations can introduce uncertainty and volatility into global supply chains. Sudden currency devaluations can disrupt the company's supplier relationships, increase the cost of imported components like PV solar panels and related components, or lead to delays in shipments. Such disruptions can impact the production schedules and overall efficiency of the company.

<u>Trade policy changes</u>

Trade policy changes are a kind of macroeconomic disruptor that refers to the modifications, adjustments, or reforms made by governments to the rules, regulations, and measures that govern international trade between countries. These changes can encompass a wide range of actions and policies, including tariffs and custom duties or for instance export controls and sanctions. The difficulties derived from these sorts of disruptor may end up causing the following issues:

- Supply Chain Complexity: Trade policy changes, such as the renegotiation of trade agreements or the introduction of new regulations, can increase the complexity of supply chains, especially for the companies that need to operate with other countries. Companies may face additional documentation requirements, customs procedures, or compliance obligations, leading to potential delays and administrative burdens in the movement of goods across borders.
- Supplier Relationships: Changes in trade policies can impact relationships with suppliers, particularly if there are shifts in trade dynamics or the imposition of tariffs. Companies like Continental Electric may need to reassess their supplier networks, explore alternative sourcing options, or even consider localizing their supply chains to mitigate risks associated with trade policy uncertainties.
- Market Volatility: Trade policy changes can introduce volatility and uncertainty into the market. Some companies may experience fluctuations in demand as tariffs, quotas, or trade restrictions are implemented or lifted. This can disrupt production planning and inventory management for companies like Continental Electric, requiring them to be agile and responsive to changing market conditions.
- Trade Compliance Costs: Trade policy changes will probably increase compliance costs for companies, especially if there are new licensing requirements, certifications, or quality standards to meet. Companies probably will be required to invest in systems and resources to ensure compliance, which can impact their overall supply chain costs.
- Trade Disputes and Geopolitical Factors: Trade policy changes can sometimes lead to trade disputes or geopolitical tensions between countries. Escalating trade conflicts, retaliatory measures, or diplomatic strains can disrupt global supply chains, increase import/export restrictions, or even lead to the reconfiguration of trade alliances. Companies like Continental Electric Construction may need to closely monitor these developments and adjust their supply chain strategies accordingly.

TECHNOLOGICAL DISRUPTORS

This third section of the supply chain analysis will revolve around the technological disruptions. According to Chapter 2, technological disruptors were those challenges associated with changes in manufacturing processes, advancements in technology, or logistic and transportation issues. Taking into consideration this, here are some of the issues pertaining to this group that are affecting not just Continental Electric, but also other procurement and construction companies:

Containers transportation issues

Nowadays, the principal mode of transportation for international shipments of products, particularly in the maritime industry, is the container. In the case of strategic materials like the PV panels purchased by Continental Electric, containers are also the main transportation mode since these materials need to be transported from countries where semiconductor-based products are assembled. Since containers are constructed in conventional sizes, they can be effectively moved from one mode of transportation to another without having to be opened. Standardized containers have revolutionized the shipping and transportation sectors, making it simple to transfer goods by rail, road, and ship. This is because the containers are designed to simply fit onto various modes of transportation.

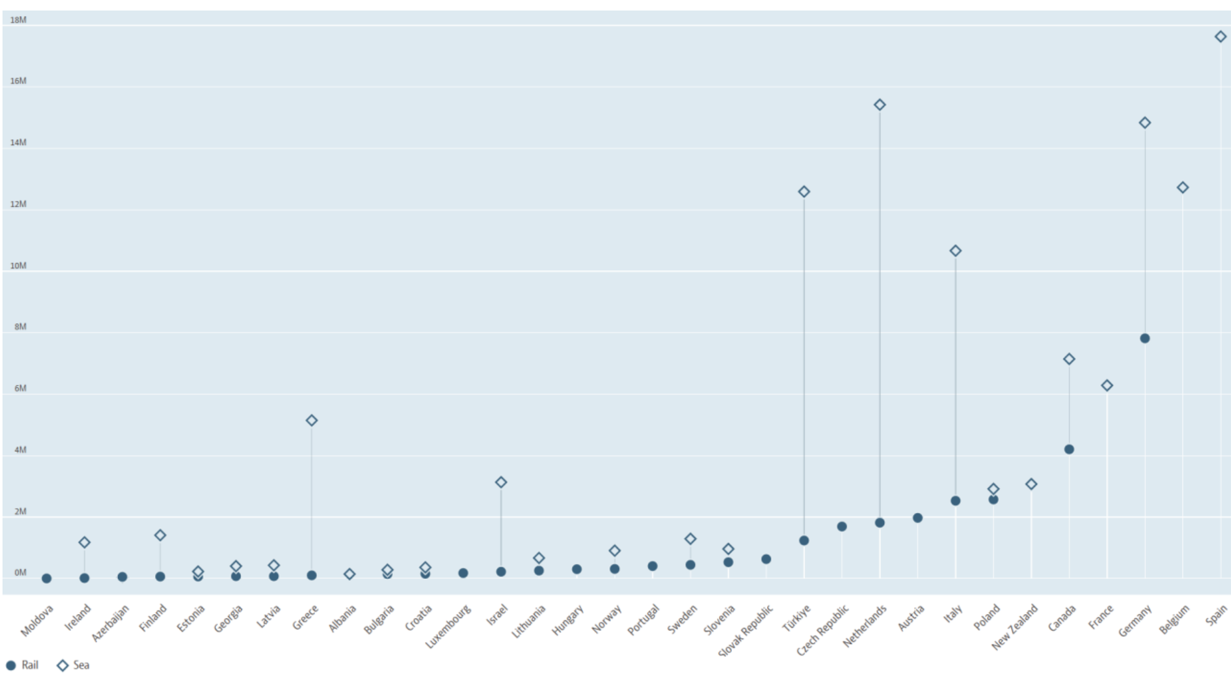

Figure 9. Quantity of TEU containers yearly transported per country. (Source: Statista 2022).

[21]According to recent data extracted from the OECD (Organization for Economic Co-Operation and Development) website, the demand for TEU containers in developed countries like Germany or Netherlands has increased up to more than 30 million, adding sea and rail transport, as can be seen in the figure above. The TEU (Twenty-foot Equivalent Unit) is a standard measurement of containers of various capacities and used for characterizing the capacity of container ships or terminals. It is based on a container of 20-foot length (6.10 m) which means that one TEU is equal to one 20-foot container. Due to this increase in popularity of this transportation mode, some issues affecting global supply chains like the PV panels supply chain of Continental Electric have appeared:

- Containers availability: The shortage of containers can disrupt the supply chain of PV panels and related components. Containers are crucial for the transportation of goods across long distances, especially in international trade. The scarcity of containers can lead to delays in shipping and logistics, affecting the timely delivery of PV panels and potentially impacting project schedules. Another disadvantage apart from the overall disruption of the PV panels supply chain is the higher shipping costs that container transportation-based companies may allocate to Continental Electric. The limited availability of containers can drive up shipping costs. When the demand for containers exceeds supply, shipping rates tend to rise. This can result in higher transportation expenses for companies like Continental Electric which may need to adjust their budgets and pricing accordingly.
- Transoceanic container ship traffic jam: The rise in popularity of containers as the preferred transportation mode has also led to ship traffic jam issues in some of the principal maritime ports across the world like the case of [22]Suez Canal in March 2021. Some of these issues include port congestion and inefficiencies to handle more ships than the capacity of the port, vessel queue and delays outside where container ships may be forced to wait outside ports or anchor at designated waiting areas due to congestion, or even increased costs for companies like Continental Electric because in some cases extended waiting times can lead

[21] Organization for Economic Co-operation and Development (OECD): Container transport (2023), website. Retrieved from: Transport - Container transport - OECD Data
[22] CNBC Africa: What's causing the container ship traffic jam clogging up global trade, article (2nd July 2021). Retrieved from: What's Causing The Container Ship Traffic Jam Clogging Up Global Trade - CNBC Africa

to higher demurrage and detention charges, which are fees imposed on containers that exceed their allotted time at the port.

- Rail container transportation: The railroad mode of transport for containers is facing challenges as well. While the volume of shipments may not be as high as transoceanic transport, many companies like Continental Electric Construction have relied on rail transportation to receive inventories, leading to associated issues. Recent data shows that the [23] United States is one of the top countries utilizing this mode of transportation. However, the railroad industry encounters difficulties such as railcar shortages and poor infrastructure, which significantly disrupt the supply chain of Continental Electric Construction's PV panels. Rail transportation serves as the final step in the acquisition process, and the panels must travel long distances to reach the company's headquarters in Chicago. These challenges are considered key disruptors in the company's supply chain.

ENVIRONMENTAL DISRUPTORS

Understanding environmental disruptors is essential for businesses as they face the challenges posed by these factors in their supply chains. As was stated in previous chapters, the environmental disruptors encompass a wide range of influences, including natural disasters, climate change impacts, resource depletion, and evolving sustainability regulations. These disruptors can have significant impacts on supply chain operations, affecting everything from sourcing raw materials to manufacturing processes and transportation logistics. Some of the environmental disruptors related to the disruption of the solar PV panels supply chain are the following:

Fossil fuels depletion

Fossil fuel depletion has emerged as a pressing concern in today's world, as the Earth's finite reserves of coal, oil, and natural gas continue to diminish. These non-renewable energy sources have fueled human civilization's remarkable growth and development over the past centuries. However, as consumption rates rise and extraction techniques become more sophisticated, the reality of dwindling fossil fuel supplies is becoming increasingly evident. The

[23] Ian Putzger. The loadstar: Now US intermodal rail yards clog up as port congestion and delays continue, article (4th September 2021). Retrieved from: Now US intermodal rail yards clog up as port congestion and delays continue - The Loadstar

consequences of fossil fuel depletion extend beyond mere scarcity; they encompass environmental, economic, and social implications that require urgent attention. The implications of the depletion of fossil fuels in the context of supply chains like the PV panels supply chain can lead to severe consequences:

- Increased fuel costs: Fossil fuels, such as gasoline and diesel, are commonly used to power vehicles, ships, and airplanes that transport goods across the supply chain. As fossil fuel resources deplete, there may be challenges in meeting the energy demands for transportation. This could result in increased fuel costs, reduced availability of transportation options, and potential disruptions to the timely movement of goods. This fact can severely affect the supply chain of Continental Electric, leading to suppliers allocating higher transportation and freight costs to the company when acquiring strategic materials.
- Energy costs: Fossil fuel depletion can lead to higher energy costs, including electricity and heating fuel, which can impact manufacturing facilities, warehouses, and other supply chain infrastructure. Higher energy costs can affect the overall cost structure of supply chains, potentially leading to increased production expenses and higher prices for end consumers.

Semiconductors depletion

The issue of semiconductors shortage in the context of technologic companies has been a topic of discussion and concern in recent years, but it is not a new problem. For instance, the first reports of potential lithium shortages can be traced back to the mid to late 2000s, when the first commercialization of lithium-ion batteries in this case for EVs started gaining momentum. As the demand for lithium-ion batteries for EVs increased, concerns were raised about the availability of lithium, which is a key component in these batteries. Lithium, like most existing semiconductors, is a finite resource and is primarily extracted from lithium-rich brine deposits or hard rock deposits. The concern was that the growing demand for lithium for use in EV batteries could potentially outstrip the available supply, leading to shortages and increased prices. This fact can be clearly observed when looking at the following figure:

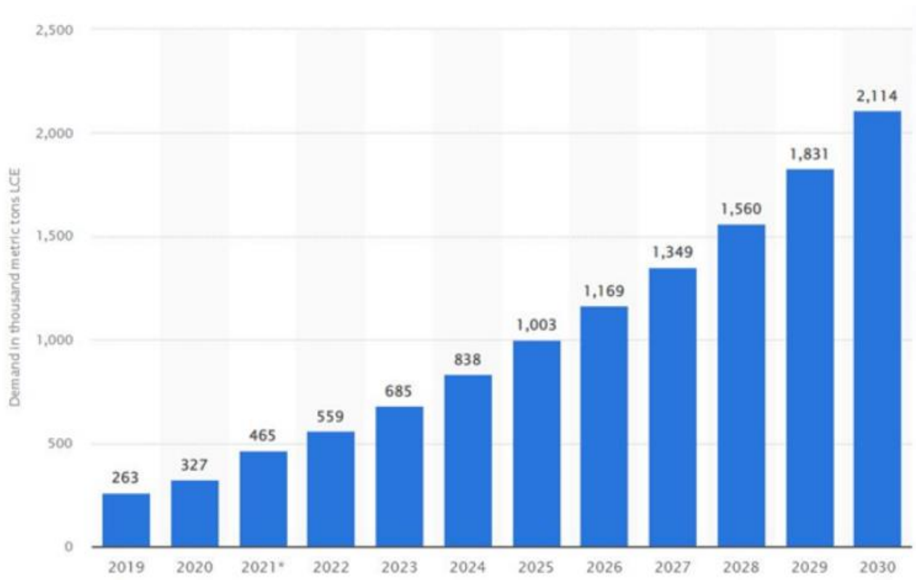

Figure 10. Projection of lithium demand from 2019 to 2030 (Source: Statista 2022).

We can clearly state that the demand for this kind of mineral will be almost ten times more in 2030 than it was in 2019, which will probably lead to unmatched supply and demand. As happens with lithium in electric vehicles, the use of silicon is basic for the PV panels manufacturing process. Silicon solar cells dominate the market due to their established manufacturing processes that were explained in chapter 2.1.3 PV panels manufacturing process, as well as their reliability, and proven performance. However, research and development efforts are ongoing to explore alternative semiconductor materials, such as thin-film solar cells based on materials like cadmium telluride (CdTe) and copper indium gallium selenide (CIGS), which offer different performance characteristics and potential cost advantages.

According to the [24] US Geological Survey, there are existing worldwide reserves of semiconductor materials that stand at about 22 million tons, which means that theoretically are sufficient reserves to satisfy the forecasted needs for the following years. However, this assumes that all the material coming from the reserves can be successfully brought into semiconductor-based gadgets, which is highly unlikely. Firstly because of the difficulties accessing some of the places where the reserves are located. Additionally, the mining and refining semiconductors processing appears to be a limiting factor, as many industries responsible for these kinds of

[24] US Department of the interior – US Geological Survey: Mineral commodity summaries 2022, survey (2022). Retrieved from: Mineral Commodity Summaries 2022 (usgs.gov)

transformations usually take an [25]average of 16.5 years to develop and start delivering the expected output. The implications of the depletion of semiconductors in the context of PV panels supply chain can lead to severe consequences, since it is the main raw material required to be manufactured:

- Reduced PV Panel Availability: Semiconductor depletion can result in a reduced availability of PV panels in the market. PV panel manufacturers and distributors are facing challenges in obtaining an adequate supply of semiconductors, which are critical components in PV panel production. This scarcity can lead to a limited supply of PV panels, making it difficult for installers and customers to access the desired quantity and variety of panels.
- Increased PV Panel Prices: When semiconductor supply is limited, it can drive up the prices of PV panels. The scarcity of semiconductors raises manufacturing costs for PV panel manufacturers, who may pass these additional expenses onto customers. As a result, the cost of PV panels can increase, potentially making solar energy systems less affordable for residential, commercial, and utility-scale projects.
- Project Delays and Uncertainty: Semiconductor shortages can lead to project delays in the PV industry. Installers and developers may face challenges in securing an adequate supply of PV panels to complete their projects on time. Delays in panel delivery can disrupt project schedules, increase project costs, and introduce uncertainty in the overall planning and execution of PV installations.
- Imbalance in Supply and Demand: Semiconductor depletion can create an imbalance between the demand for PV panels and the available existing supply. As demand for solar energy systems continues to grow, particularly with increasing adoption of renewable energy, a scarcity of semiconductors can reduce the ability of PV panel manufacturers to meet this demand. This imbalance can result in longer lead times for acquiring PV panels and diminish the expansion of solar energy capacity.

[25] International Energy Agency: The role of Critical Minerals in Clean Energy Transitions, survey (May 2021). Retrieved from: The Role of Critical Minerals in Clean Energy Transitions (windows.net)

Climate change and natural disasters

Climate change is one of the most significant and pressing challenges of our time. It refers to long-term shifts in global weather patterns and the Earth's climate system, largely attributed to human activities. The burning of fossil fuels, deforestation, industrial processes, and other human-induced activities have led to an unprecedented increase in greenhouse gas emissions, trapping heat in the atmosphere and causing a range of adverse effects. These effects include rising temperatures, melting ice caps and glaciers, sea-level rise, altered precipitation patterns, and more frequent and intense extreme weather events. Climate change poses a threat to ecosystems, biodiversity, human health, and socio-economic stability, making it a global concern that requires urgent attention and concerted efforts to mitigate its impacts and build resilience for a sustainable future. As happens with the other disruptors, climate change can impact the PV solar panels supply chain in several ways as well. Some key points on how climate change can affect the PV solar panels supply chain are:

- Raw Material Availability: Climate change can affect the availability and accessibility of raw materials used in PV panel production. For example, extreme weather events like hurricanes, floods, or droughts can disrupt mining operations or damage infrastructure, leading to disruptions in the supply of materials such as silicon, silver, aluminum, and other components necessary for PV panel manufacturing.
- Energy Production and Efficiency: Climate change can influence the performance and efficiency of PV panels due to changes in temperature and solar irradiance. Higher temperatures reduce the efficiency of PV panels, leading to decreased energy output. Changes in solar radiation patterns, cloud cover, and air pollution can also affect the overall energy production of PV systems, impacting their economic viability and reliability.
- Physical Damage and Resilience: Climate change-related events, such as severe storms, hurricanes, wildfires, or other natural disasters can cause physical damage to the different agents pertaining to the PV panel supply chain, especially to manufacturers located in places with risk of suffering from natural disasters like Taiwan or other Asiatic countries.
- Supply Chain Disruptions: Climate change impacts, such as extreme weather events or disruptions to transportation networks, can lead to supply chain disruptions for PV solar panels. Disruptions in logistics, including delays in transportation and delivery, can affect

the availability of PV panels, installation schedules, and overall project timelines. This can create challenges for PV manufacturers, installers, and project developers in meeting customer demands and fulfilling project commitments.

- Policy and Regulatory Changes: Climate change mitigation efforts often involve policy and regulatory changes that can influence the PV solar panels supply chain. Governments may implement measures such as renewable energy targets, carbon pricing mechanisms, or energy efficiency standards that shape the demand for PV panels and impact the market dynamics. Adapting to evolving regulations and ensuring compliance become important factors in managing the PV supply chain.

GEOGRAPHIC DISRUPTORS

As was explained at the end of chapter 2, geographic disruptors are disruptions that occur due to political instability, or other events that can impact specific regions or countries. Some of the geographic disruptors that are affecting PV panels supply chain are:

Suppliers' location

Nowadays, the global nature of supply chains means that businesses are increasingly interconnected across various regions, making them vulnerable to disruptions that can arise from geographical factors. In the semiconductor industry, the biggest part of tier 1 manufacturers is in countries with abundance of this material, since it can be directly extracted from the reserves and treated for manufacturing purposes, avoiding additional transportation costs to other locations. Some of these countries include Democratic Republic of Congo, China, Australia, Taiwan, or Brazil. According to the data extracted from Continental Energy, their main suppliers that are essentially PV panels manufacturers are in Taiwan. In long and complex supply chains, the distance to the manufacturer can represent a big problem for most companies:

- Increased Lead Times: Longer distances between the company and the manufacturer can result in extended lead times for the delivery of raw materials, components, or finished products. Transportation and logistics processes, including customs clearance and shipping, take more time, leading to delays in receiving the necessary inputs. These delays can disrupt production schedules and impact on the company's ability to meet customer demand in a timely manner.

- Higher Transportation Costs: Shipping goods over long distances typically involves higher transportation costs. Fuel expenses, freight charges, and other logistical expenses can add up, affecting the overall cost structure of the supply chain. Companies may need to factor in these increased costs when pricing their products or optimizing their supply chain networks.
- Inventory Management Challenges: Managing inventory becomes more complex when there are large distances between the company and the manufacturer. Holding excessive inventory can tie up working capital and increase the risk of obsolescence or damage. On the other hand, maintaining low inventory levels increases the vulnerability to supply disruptions due to longer replenishment lead times. Finding the right balance in inventory management becomes crucial for efficient supply chain operations.
- Communication and Coordination: Effective communication and coordination become more challenging when there are physical distances involved. Time zone differences, language barriers, and cultural nuances can hinder clear communication and collaborative decision-making between the company and the manufacturer. It requires establishing robust communication channels, leveraging technology, and implementing effective coordination mechanisms to bridge these gaps.
- Quality Control and Product Integrity: Managing quality control and ensuring product integrity across long distances can be complex. Without proximity to the manufacturer, the company may face challenges in conducting timely inspections, monitoring production processes, and ensuring adherence to quality standards. Implementing quality assurance measures, regular audits, and maintaining strong supplier relationships are crucial to mitigating quality-related risks.

As has been explained in this chapter, the modern business landscape is filled with numerous disruptors that can significantly impact supply chains. From currency exchange rate fluctuations and trade policy changes to container shortages, geographic challenges, and the depletion of fossil fuels, companies face a complex web of factors that can disrupt their supply chain operations. Additionally, the emerging threats posed by climate change and the depletion of semiconductor materials add further complexity to supply chain management. To navigate these challenges successfully, organizations must prioritize resilience, agility, and proactive planning.

This includes diversifying sourcing strategies, developing robust communication channels, fostering strong supplier relationships, adopting sustainable practices, and leveraging technology for enhanced visibility and optimization, but all these strategies will be reviewed more accurately in the following chapter. By understanding and addressing these disruptors head-on, companies can position themselves for a more resilient and sustainable supply chain ecosystem, ensuring their ability to meet customer demands, mitigate risks, and thrive in a dynamic business environment. Before moving forward with the following chapter, a summarizing table with all the disruptors that have been discussed during the chapter is displayed below:

Table 2. Disruptors of Continental Electric's Solar PV panels Supply Chain.

<table>
<tr><th colspan="3">DISRUPTORS</th></tr>
<tr><td rowspan="3">Operational</td><td colspan="2">1. Purchasing procedures</td></tr>
<tr><td colspan="2">2. Centralized purchasing department</td></tr>
<tr><td>3. Inventory shortage</td><td>3.1 Project policies
3.2 Warehousing strategies
3.3 Forecasting models
3.4 Suppliers shortage</td></tr>
<tr><td rowspan="3">Macroeconomic</td><td colspan="2">4. Economic recession</td></tr>
<tr><td colspan="2">5. Currency exchange rate</td></tr>
<tr><td colspan="2">6. Trade policy changes</td></tr>
<tr><td>Technological</td><td>7. Containers transportation</td><td>7.1 Containers availability
7.2 Transoceanic ship traffic jam
7.3 Rail container transportation</td></tr>
<tr><td rowspan="3">Environmental</td><td colspan="2">8. Fossil fuel depletion</td></tr>
<tr><td colspan="2">9. Semiconductors depletion</td></tr>
<tr><td colspan="2">10. Climate change and natural disasters</td></tr>
<tr><td>Geographic</td><td colspan="2">11. Suppliers location</td></tr>
</table>

CHAPTER 4
SOLUTIONS

In an increasingly complex and unpredictable business environment, Continental Energy faces a range of disruptors that can significantly impact its supply chain operations. These disruptors, such as currency exchange rate fluctuations, container shortages, trade policy changes, geographic challenges, and resource depletion, pose risks and challenges that demand effective solutions. This chapter will focus on leveraging Supply Chain Management techniques as the primary tool to address and overcome these disruptors. By applying strategic sourcing, supplier diversification, optimized inventory management, advanced technology integration, collaborative partnerships, risk management practices, and sustainable initiatives, Continental Energy can build a resilient and agile supply chain. By utilizing Supply Chain Management techniques specifically tailored to combat the challenges posed by these disruptors, the company can proactively mitigate risks, enhance operational efficiency, and ensure continuity in its supply chain. This chapter aims to provide practical insights, best practices, and actionable solutions that empower Continental Energy to effectively navigate the complexities of the business landscape and drive its supply chain towards greater resilience, adaptability, and long-term success.

4.1 IMPLEMENTATION OF POTENTIAL SOLUTIONS

From a Supply Chain Management perspective, there are several key strategies that are frequently used to make Supply Chains more efficient, agile, and resilient to changes or unpredictable disruptions. These strategies go from implementing a new distribution network of suppliers and providers to others radically different like renegotiating the existing supply contracts. The idea of this section is to propose a wide range of detailed Supply Chain Management strategies addressed to the specific needs of Continental Energy, taking into consideration the disruptors explained previously to deliver a clear, understandable, and effective plan to the company. With this plan, the company should be able to significantly reduce solar PV panels lead times up to at least 1% as was stated in the objectives of the project. According to some data extracted from the company, the most commonly type of panel purchased in the company is the Hanwha Q cell 400W panel. This was determined after performing an ABC analysis on the main types of panels that Continental Energy was purchasing to different suppliers:

Table 3. ABC analysis of different PV panel suppliers.

Supplier	Average price [$/W]	Number of panels of 400 W purchased per year	Total	Marginal Percentage	Accumulated Percentage	Category
Hanwha Q CELLS	0.85	200,000	$ 68,000,000	80%	80%	A
SunPower Panels	0.9	30,000	$ 10,800,000	13%	92%	B
LG Solar Panels	0.8	12,000	$ 3,840,000	4%	97%	C
REC Solar	0.7	10,000	$ 2,800,000	3%	100%	C
TOTAL		**252,000**	**$ 85,440,000**		**100%**	

According to the ABC methodology, 80% of the total disbursements of the company in solar panels has been for the Hanwha Q cells PV panels, which means that this group is considered as A products in terms of importance for the company. In this case, PV panels purchased from SunPower Panels will represent family B, and LG Solar Panels and REC solar will represent family C, which are essentially the least important category of products for the company in terms of payout. Taking into consideration this analysis, the 1% reduction in Lead Time will be applied to the Q cells to simplify the problem and make an impact on the core part of the business.

Once this point is clarified, the next step will be to introduce the different strategies on which Supply Chain Management must be focused. These key topics are the following, and along the chapter we will review some of them:

- Network planning
- Inventory Management
- Supply Contracts
- Purchasing & Production sourcing
- Distribution strategies
- Supply Chain Integration and Strategic Partnering
- Outsourcing and Offshoring Strategies

4.1.1 Network planning

As was stated at the beginning of chapter 3, the physical supply chain consists of suppliers, plants, warehouses, distribution centers, and retail outlets as well as raw materials, and finished products that flow between the facilities. Network planning refers to the process by which the firm or business structures and manages its supply chain. This strategy essentially aims to help the company by:

- Finding the right balance between inventory, transportation, and manufacturing or distribution costs.
- Matching supply and demand under uncertainty by positioning and managing inventory effectively.
- Utilizing resources effectively by sourcing products from the most appropriate manufacturing facility.

The first step within a network planning process is to gather data regarding the actual state of the company. A typical network configuration problem involves large amounts of data, including information on:

- Locations of customers, retailers, existing warehouses and distribution centers, manufacturing facilities, and suppliers.
- All products, including volumes, and special transport modes (e.g., refrigerated). 3.
- Annual demand for each product by customer location.

After collecting the necessary data, the next step is to leverage this information to make an initial assessment of the company's status, focusing on economic expenditures, transportation time, and other relevant factors. Once this assessment is complete, the objective is to identify potential improvements for the existing system by suggesting alternative network configurations, and considering additions or reductions in functions, warehouses, offices, and other relevant components. Lastly, it is crucial to evaluate whether implementing these changes will provide measurable advantages in terms of cost-effectiveness and timeliness for the company. This evaluation will help determine the potential economic and time-related benefits that can be derived from the proposed modifications.

1) Network planning: Data collection

Distribution of solar PV projects

In our case, the first data we have regarding this problem is the distribution of solar PV installations that Continental Energy performs across the US, which can be observed in figure 11:

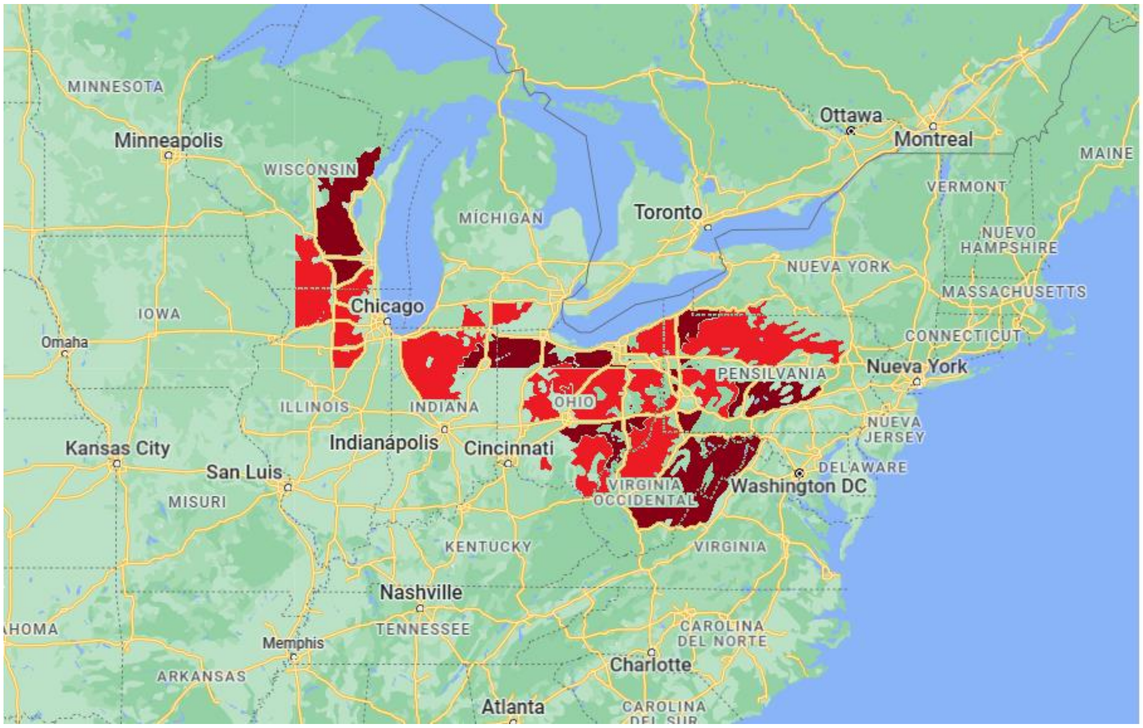

Figure 11. Distribution of customer's worksite location.

As can be seen in the map, the red zones imply a low to normal density of projects while the maroon color zones represent normal to high density of installations performed. Taking into consideration the information provided by the map, the biggest part of the projects take place in Ohio, Pennsylvania, Virginia, Indiana, Wisconsin, and northern part of Illinois.

Distribution of headquarters and warehouse

Continental Energy has 1 office and 1 warehouse for tool storage, both located in Oakbrook Terrace, Illinois, as can be seen in figure 12.

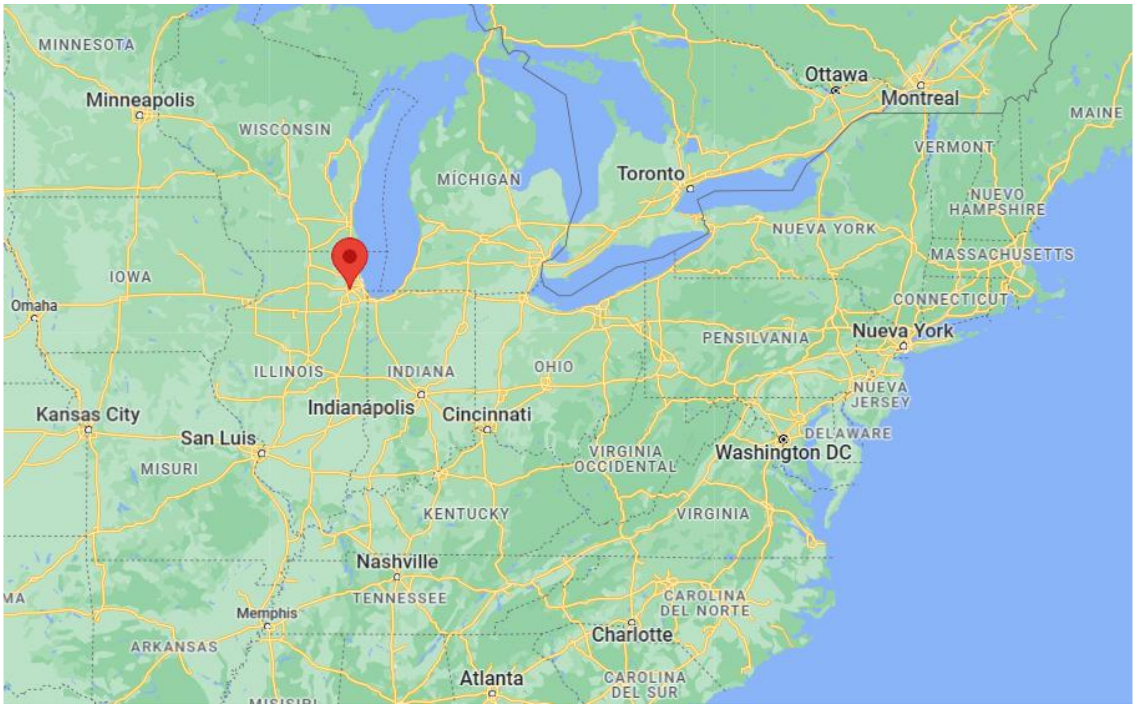

Figure 12. Location of current Continental Energy's headquarters and warehouse.

When Continental Energy was initially established, the majority of its projects and employees were concentrated in the northern part of Illinois. This geographical proximity led to the company establishing its headquarters in that location. Despite this, most of the company's projects are now situated in the eastern part of the United States, specifically in Ohio, Pennsylvania, West Virginia, as well as some in Illinois and Wisconsin.

<u>Freight rail map</u>

As has been seen previously, the gross of projects was in the eastern part of the country, specifically in Ohio, Pennsylvania, and West Virginia, but also some take place in Illinois and Wisconsin. The aim of this section is to determine:

1) The railroad map and miles that freight companies need to do to deliver their Solar PV panels to Continental Energy's headquarters.
2) The road map that Continental Energy needs to carry the PV panels from their headquarters to the specific installations by truckload.

It's important to note that Continental Energy's purchasing policies prevent them from commencing work on a project until they have received the panels for that specific project. As a result, they are unable to order the panels in advance. To overcome this challenge, the company arranges for the panels to be delivered to their headquarters before forwarding them to the respective installation sites. For this analysis, we will focus on four different project locations: Wisconsin, Ohio, Pennsylvania, and West Virginia, as depicted in Figure 13 with designated spokes.

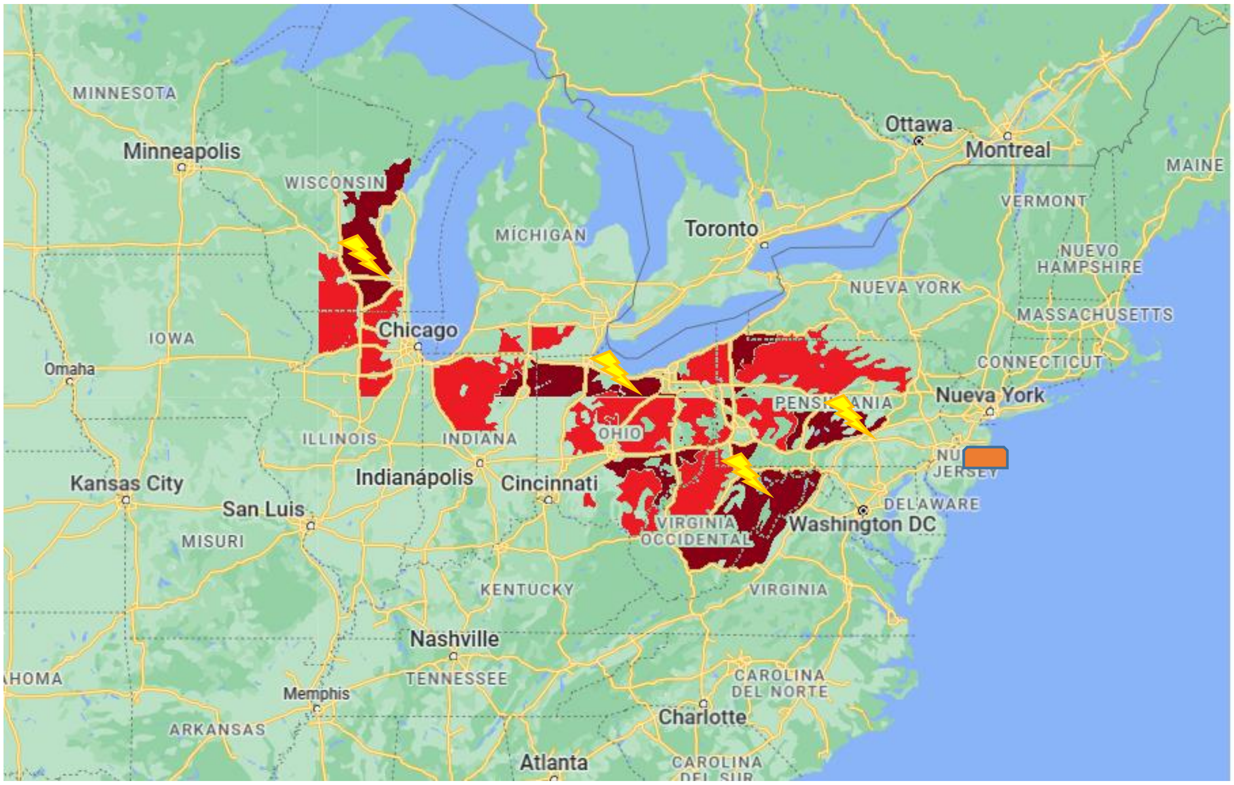

Figure 13. Distribution of 4 main installations to compute freight costs.

To calculate the total distances that freight railroad companies need to complete to deliver the ordered solar PV panels, we need to consider that these inventories arrive from the port of Newark-Elizabeth Marine Terminal in New Jersey which is one of the busiest ports for imports and a significant entry point for various goods, including solar PV panels. The Port of Newark is located near the metropolitan area of New York City and serves as a major hub for international trade, and is marked with an orange filled-shape in figure 13.

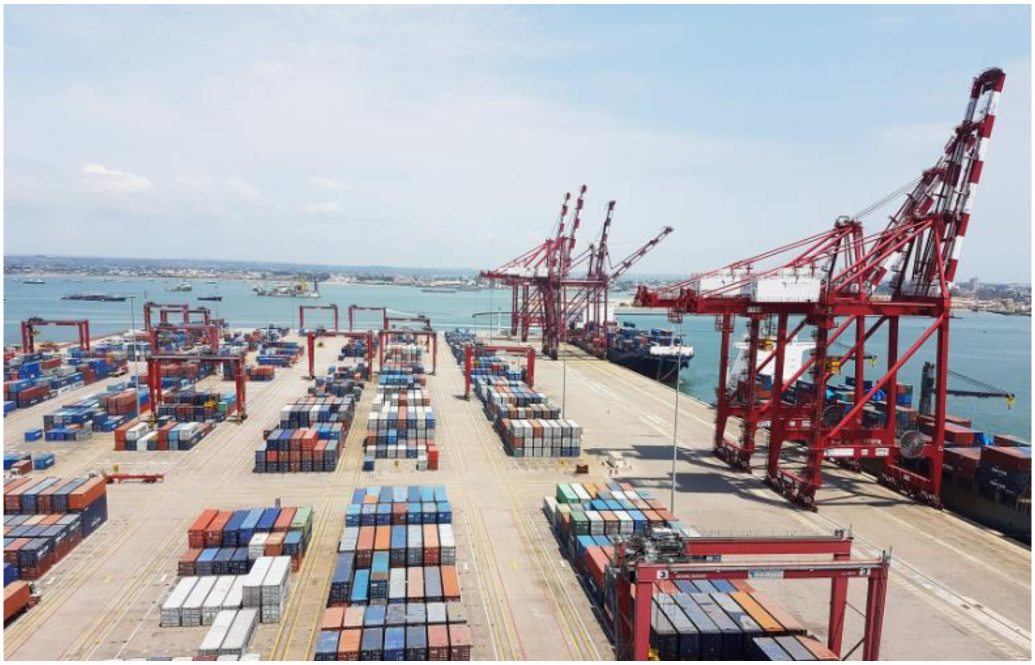

Figure 14. Newark Elizabeth Port in New Jersey. (Source:AllCityAerial.com).

It has extensive container terminal facilities and is well-connected to transportation networks, making it a preferred port for importing goods into the East Coast region for inventories coming from Semiconductor manufacturing countries like Taiwan or China.

This port can be identified within the map of figure 13 as an orange-filled shape. The overall distance between Continental Energy's Headquarters and the Newark Elizabeth Port can be observed in table 4.

Table 4. Distances between Port and Headquarters.

Origin Point	**Ending Point**	**Total distance CSX [miles]**	**Total distance NS [miles]**	**Average total distance [miles]**
Newark-Elizabeth Terminal	Oakbrook Terrace	918	930	924

Even though [26]distances depend on the railway company that Continental Energy would pick for their PV panels orders, we can see there are similar and that's the reason why it has been decided to consider from now on the average distance of both companies.

[26] Aberdeen Carolina & Western Railway Company. Distances have been calculated with this software. Retrieved from: Freight Rail Map of Class I Carriers in North America - ACW Railway Company

Figure 15. Railroad map for CSX Intermodal.

Figure 16. Railroad map for Norfolk Southern.

On the other hand, once the PV panels need to be sent from the headquarters to the specific location where they will be installed, the most common practice for companies in the solar industry like Continental Energy is road transportation. In the table below appears the total road distance between the headquarters and the 4 installation projects:

Table 5. Total distance between Headquarters and installations.

Origin Point	Ending Point	Total distance [miles]
Oakbrook Terrace	Wisconsin	113
Oakbrook Terrace	Ohio	360
Oakbrook Terrace	Pennsylvania	660
Oakbrook Terrace	West Virginia	640

2) Network planning: Data interpretation

Based on the collected data, it appears that the transportation process for PV panels involves an initial leg of the journey by railroad to reach the company's headquarters. Subsequently, the panels are transported from the headquarters to each installation site using road transportation, typically through truckload shipments. Regarding railroad transportation, according to the [27]official tariffs of CSX and NS the average price per mile for products with similar characteristics is $0.65/car x mile. Moreover, we have the following data:

- Average demand for PV panels per year: 200,000 Hanwha Q cells panels/year = 16,666 Hanwha Q cells panels/month.
- Railroad car capacity: 200 panels/railroad car.

$$Demand\ for\ cars = \frac{Monthly\ Q\ cell\ panels\ demand}{Railroad\ car\ capacity} = \frac{16{,}666\ \frac{panels}{month}}{200\ \frac{panels}{car}} = 84\ cars/month$$

Equation 1. Calculation of Continental Energy's monthly demand for railcars.

Based on the computed data, we can determine that the average demand for railroad cars to the headquarters is approximately 84 cars per month. By combining this figure with the average price per car per mile and considering the total distance from the New Jersey Port to the headquarters, which is measured to be 924 miles, we can estimate that **Continental Energy** incurs a total **monthly expense of $50,450.40 for transporting PV panels to their headquarters,** as can be seen in equations 2 and 3:

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[27]Norfolk Southern: NS 8001-A Switching and absorption tariff, tariff (30th September 2022). Retrieved from: NS-8001-A-Effective-10-20-22.pdf (nscorp.com)

$$PV\ panels\ transportation\ NJH\ expenses = Demand\ for\ cars \times Average\ price\ mile\ car\ \times NJH\ Miles$$

Equation 2. Formula to compute expenses on PV panels transportation from New Jersey to Headquarters.

$$PV\ panels\ transportation\ NJH\ expenses = 84\ \frac{cars}{month} \times \frac{\$0.65}{car \times mile} \times 924\ miles = \$50{,}450.40$$

Equation 3. Calculation of expenses on PV panels transportation from New Jersey to Headquarters.

When considering road transportation, it's important to distinguish between Full Truckload (FTL) and Less Than Truckload (LTL) shipments. In the case of Continental Energy, it is generally necessary to opt for FTL shipments due to the significant quantity of panels being transported. As a rough estimate, approximately 500 panels can be accommodated in a single FTL shipment.

$$Demand\ for\ FTL = \frac{Monthly\ Q\ cell\ panels\ demand}{FTL\ capacity} = \frac{16{,}666\ \frac{panels}{month}}{500\ \frac{panels}{FTL}} = 34\ FTL/month$$

Equation 4. Calculation of monthly demand for Full Truckloads.

Based on the research conducted by the [28]American Transportation Research Institute, the average trucking cost for logistics companies in the United States is approximately $1.82 per mile. For our calculations, we will consider this value to determine the total transportation cost for delivering the panels from Continental Energy's Headquarters to each of the four specified installations. Considering the total distance in miles for each installation, we can compute the overall expenses for each installation. It is important to note that an equalized distribution of 25% of the PV panels is allocated to each project. This means that a monthly delivery of 4,167 panels is made to each project on an equal basis. By applying the average trucking cost per mile, we can calculate the total expense for transportation to each installation, as shown in Table 6:

[28] Transplus: The true cost per mile of the transportation and logistics industry. Retrieved from: The True Cost Per Mile of the Transportation and Logistics Industry (transplus.io)

Table 6. Monthly expenses for PV transportation: Headquarters to installations.

Origin Point	Ending Point	Total distance [miles]	Price per mile [$/mile]	Number of FTL	Total expenses
Oakbrook Terrace	Wisconsin	113	1.82	8.5	$ 1,748.11
Oakbrook Terrace	Ohio	360	1.82	8.5	$ 5,569.20
Oakbrook Terrace	Pennsylvania	660	1.82	8.5	$ 10,210.20
Oakbrook Terrace	West Virginia	640	1.82	8.5	$ 9,900.80
TOTAL		**1,773**	**1.82**	**34**	**$ 27,428.31**

Taking into consideration all these calculations, we can state that Continental Energy incurs in a total monthly expenditure of $77,878.71 to transport their panels from the arrival port in New Jersey's Marine Terminal to their customers installation.

Table 7. Total monthly expenses for PV transportation.

PV panels' transportation mode	Origin Point	Ending point	Expenditure	Percentage of expenditure
Railcar	New Jersey Port	Headquarters	$ 50,450.40	64.8%
FTL	Headquarters	Customer's installation	$ 27,428.31	35.2%
TOTAL			**$ 77,878.71**	**100.0%**

3) Future state

The final step in this Supply Chain Management technique involves analyzing the available data and proposing practical solutions to enhance the existing transportation system. One highly beneficial approach to improving this system is to minimize the distance and time required for PV panels to reach their ultimate destination. A key observation is that projects in the Eastern part of the US tend to be less efficient, as the panels must travel in the opposite direction to reach the company's headquarters first. To mitigate costs, a potential solution would involve establishing a new warehouse in the Eastern part of the US. This arrangement would enable the delivery of PV panels directly to the Eastern projects upon their arrival at New Jersey's Port. Implementing this solution would reduce railroad miles and eliminate the need for road transportation companies to travel greater distances starting from the headquarters. Instead, they could begin their journeys from a warehouse in closer proximity to the Eastern projects, streamlining the overall logistics process and reducing costs. Among the various possible locations for the new warehouse, Ohio emerges as the most favorable choice due to its advantageous proximity to the other Eastern projects and its competitive rental prices. Considering factors such as accessibility and cost-effectiveness, Ohio stands out as the optimal option for establishing the new warehouse. In terms of warehouse rental rates, Ohio tends to have a slightly lower cost compared to Pennsylvania and West Virginia. This is because Ohio has a larger industrial base and a more competitive market for warehouse rentals. However, the specific location within each state, such as proximity to major cities or transportation hubs, can also impact the rental rates.

After conducting a thorough analysis of [29]warehouse leasing options in Ohio, it has been determined that the most favorable choices for Continental Energy are Youngstown, Belle Vista, and Austintown. These locations offer attractive benefits, including an average rental price of $7.50 per square foot per year, equivalent to $0.63 per square foot per month.

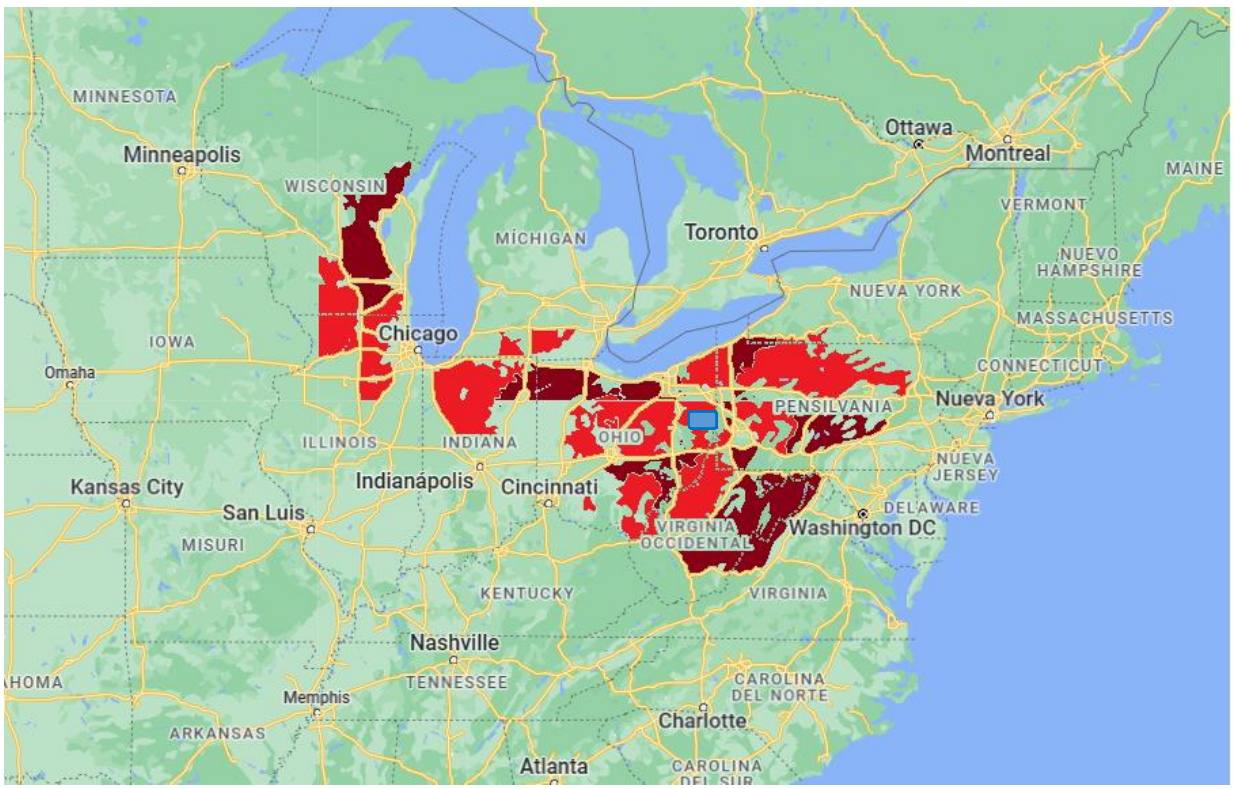

Figure 17. New potential warehouse location in Ohio.

To calculate the total square footage needed, we can use the following reasoning:

[29] Ohio Industrial Space for Lease | LoopNet

$$\text{Total Square Footage} = \text{Number of Panels} \times \text{Side area per Panel}$$

Equation 5. Formula for calculating the square footage for the new warehouse.

To determine the appropriate storage capacity for the new warehouse, we can calculate the number of panels needed based on the monthly demand and the expected inventory behavior. By allocating 75% of the monthly PV panels demand to the warehouse that will serve Ohio, West Virginia, and Pennsylvania, we arrive at a total of 12,500 panels. Considering the traditional inventory behavior over time, it can be estimated that the warehouse would not need to store the maximum 75% of the monthly demand continuously. On average, the number of panels required would be approximately two-thirds of this maximum value. Therefore, it is concluded that leasing a warehouse with a capacity of 8,400 panels would be more than sufficient to meet the monthly demand. This capacity allows for efficient storage and ensures an appropriate inventory level to support the installation projects in the designated regions.

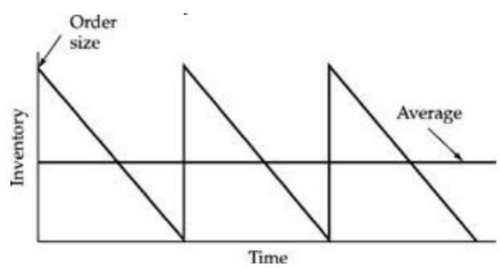

Figure 18. Inventory's behavior with time. (Source: Supply Chain Management.com)

To determine the required square footage for the new warehouse, we need to consider the side area of the PV panels. Since the panels would be stored with their main PV area facing one side to optimize space, we focus on the side panel area. The side panel area can be calculated by multiplying the length (65 inches) by the thickness (1.57 inches), which gives us 102.05 square inches. Converting this to feet, we have 0.71 square feet per panel. By multiplying this side panel area per the required capacity of the warehouse, we can determine the minimum square footage that the new warehouse should have, as shown in equation 6:

$$\text{Total Square Footage} = 8{,}400 \text{ panels} \times 0.71 \frac{SF}{panel} = 5{,}964\ SF$$

Equation 6. Calculation of Square footage for the new warehouse.

The average expected cost then for the new warehouse would be calculated with the following equation:

$$\text{Warehouse expense} = \text{Monthly SF price} \times Total\ square\ footage = \$\frac{0.63}{SF \times month} \times 5{,}964\ SF = \$3{,}587/month$$

Equation 7. Calculation of monthly warehouse expenses.

The last step of this section would be to compute the new distances that railway companies as well as logistics road companies will now do to deliver the panels. The mileage regarding the distances related to the railcar expenses, we got the information provided by table 8:

Table 8. Distances between Port and Headquarters/Warehouse.

Origin Point	Ending Point	Total distance CSX [miles]	Total distance NS [miles]	Average total distance [miles]
Newark-Elizabeth Terminal	Headquarters	918	930	924
Newark-Elizabeth Terminal	Warehouse	615	585	600

The mileage and total expenses regarding road transportation costs can be found in table 9:

Table 9. Total monthly expenses for PV road transportation with new system.

Origin Point	Ending Point	Total distance [miles]	Price per mile [$/mile]	Number of FTL	Total expenses
Headquarters	Wisconsin	113	1.82	8.5	$ 1,748.11
Warehouse	Ohio	40	1.82	8.5	$ 618.80
Warehouse	Pennsylvania	260	1.82	8.5	$ 4,022.20
Warehouse	West Virginia	220	1.82	8.5	$ 3,403.40
TOTAL		**633**	**1.82**	**34**	**$ 9,792.51**

Taking into consideration all this data, the new monthly expenses for PV panels transportation have been calculated in table 10:

Table 10. Total monthly expenses for PV transportation with new system.

PV panels' transportation mode	**Origin Point**	**Ending point**	**Expenditure**	**Percentage of expenditure**
Railcar	New Jersey Port	Headquarters	$ 12,612.60	24.6%
	New Jersey Port	Warehouse	$ 25,184.25	49.2%
Full Truckload	Headquarters	Customer's installation	$ 1,748.11	3.4%
	Warehouse	Customer's installation	$ 8,044.40	15.7%
Warehouse leasing	-	-	$ 3,587.00	7.0%
TOTAL			**$ 51,176.36**	**100.0%**

By comparing the expense structures of the existing network system with the proposed alternatives, it has been determined that significant cost savings can be achieved. The potential savings amount to approximately $26,702.35 per month, which represents a total of 34.28% reduction in monthly expenses for PV transportation, as shown in table 11:

Table 11. Comparison between monthly expenses of new and existing network.

Network distribution	**PV panels' transportation mode**	**Itemized monthly expenses [$/month]**	**Total monthly expenses [$/month]**
Existing system	Railcar	$ 50,450.40	$ 77,878.71
	Full Truckload	$ 27,428.31	
New system	Railcar	$ 37,796.85	$ 51,176.36
	Full Truckload	$ 9,792.51	
	Warehouse	$ 3,587.00	

Finally, it is crucial to highlight that the implementation of the new network system will not only help achieve the economic objectives of the project but also address the timely aspect of the supply chain. One of the project's goals was to reduce overall lead time by 1%. Although a 1% reduction may seem minor, it holds significant importance across industries. For longer lead times spanning months, a 1% improvement can translate into several days of saved time. Table 12 provides a visual representation of the mileage and time savings resulting from the implementation of the new system, showcasing the tangible benefits for the company:

Table 12. Lead Time savings in Miles and Days.

PV panels' transportation mode	Network Distribution	Average Lead Time for all installations [Miles]	Savings in average Lead Time [Miles]	Average speed [Miles/hour]	Savings in average Lead Time [Days]
Railcar	Existing system	924	243	30	1.01
	New system	681			
Full Truckload	Existing system	443	285	55	0.65
	New system	158			
TOTAL			**528**		**1.66**

As is reflected in table 12, a total of 1.66 days is saved per order. If we compute this data with the Overall Lead Time (that includes an estimated time for the order to travelling across the ocean coming from an Asian supplier) which is estimated to be 90 days, and the US territory Lead Time (which basically refers to the time that the order takes to get to customer’s installation once they are in the US territory) we obtain the following percentages of improvement:

Table 13. Lead Time improvement.

Improvements on Lead Time	Lead Time Savings [Days]	Current Lead Time [Days]	Percentage of improvement [%]
US territory Lead Time	1.66	4.86	34.17%
Overall Lead Time	1.66	90.00	1.84%

According to the table, the analysis reveals a significant improvement in the overall lead time, with a reduction of 1.84%. This reduction signifies a substantial enhancement in the efficiency and timeliness of the supply chain operations for Continental Energy. Additionally, the data shows an impressive reduction of 34.17% in lead time across the US territory, further highlighting the impactful nature of the implemented improvements.

In conclusion, the implementation of a new warehouse in the Eastern zone, along with the proposed measures, will result in improved customer service, faster assessments, reduced transportation distances, and more competitive prices. These changes will enhance the overall efficiency and effectiveness of the supply chain, benefiting both the company and its customers.

4.1.2 Inventory Management

Inventory management techniques are an integral part of supply chain management, playing a critical role in ensuring the efficient and effective flow of goods throughout the entire supply chain network. These techniques are vital for achieving several key objectives that contribute to the overall success of the organization. One of the primary goals of inventory management is to meet customer demand. By carefully managing inventory levels, companies can ensure that products are available when customers need them. This helps to avoid stockouts and backorders, which can lead to customer dissatisfaction and lost sales. By maintaining optimal inventory levels, companies can strike a balance between meeting customer demand and minimizing holding costs.

Effective inventory management also helps to balance supply and demand fluctuations. By closely monitoring market trends, customer buying patterns, and demand forecasts, companies can adjust their inventory levels and production schedules accordingly. This ensures that they have the right amount of inventory at the right time, avoiding excessive inventory carrying costs or shortages.

Reducing lead times is another critical aspect of supply chain management. By strategically positioning inventory at key locations along the supply chain, companies can minimize the time it takes to deliver products to customers. This leads to faster order fulfillment, shorter delivery times, and improved customer responsiveness. This is what was specifically covered in the first potential solution previously provided in this chapter.

Cost optimization is an essential consideration in inventory management. Excess inventory levels can result in increased holding costs, such as warehousing, insurance, and obsolescence costs. On the other hand, inadequate inventory levels can lead to stockouts and associated costs, such as lost sales and expedited shipping charges. Effective inventory management ensures that inventory levels are optimized to strike a balance between holding costs and stockout risks.

The idea of this section is to provide Continental Energy with improvements from another point of view slightly different to Network Distribution. Specifically, this section will focus on Inventory Management tools and formulas to get the optimal number of PV panels' safety stock, quantity order and reorder point that the company must meet to work under reliable conditions to avoid stockouts, excess of inventory and meet customer's demand.

There are two main models that most industries use to order from their providers depending on the specific conditions and needs of the company:

- Continuous review policy: inventory is reviewed continuously, and an order is placed when the inventory reaches a particular level, or reorder point. This type of policy is most appropriate when inventory can be continuously reviewed—for example, when computerized inventory systems are used.
- Periodic review policy: in which the inventory level is reviewed at regular intervals and an appropriate quantity is ordered after each review. This type of policy is most appropriate for systems in which it is impossible or inconvenient to frequently review inventory and place orders if necessary.

For the current case, continuous review seems to be the most appropriate model for the company because of the following reasons:

- Demand Variability: In the solar electric industry, demand for PV panels and related products can be highly variable due to factors such as seasonality, project timelines, and market trends. The continuous review model is well-suited to handle such variability as it continuously monitors inventory levels and triggers reorder points based on real-time demand data.
- Real-Time Visibility: With the continuous review model, inventory levels are constantly monitored, allowing for real-time visibility into stock levels. This helps ensure that inventory levels are always aligned with demand, minimizing the risk of stockouts or excess inventory.
- Lead Time Considerations: The continuous review model considers lead times, which is crucial in the solar electric supply chain where delivery times for PV

panels and related components can vary. By factoring in lead times, the model can calculate the reorder point to ensure that inventory is replenished in a timely manner to meet customer demand.

Before starting with this model, some assumptions need to be done:

- Daily demand is random and follows a normal distribution. In other words, we assume that the probabilistic forecast of daily demand follows a bell-shaped curve. This demand would be described by its average and standard deviation values.
- Every time the distributor places an order from the manufacturer, the distributor pays a fixed cost, K, plus an amount proportional to the quantity ordered.
- Inventory holding cost is charged per item per unit time.
- Inventory level is continuously reviewed, and if an order is placed, the order arrives after the appropriate lead time.
- If a customer order arrives when there is no inventory on hand to fill the order (for example when the distributor is stocked out), the order is lost.
- The distributor specifies a required service level. The service level is the probability of not stocking out during lead time. For example, the distributor might want to ensure that the proportion of lead times in which demand is met out of stock is 98 percent. Thus, the required service level would be 98 percent in this case.

To characterize the inventory policy that the distributor should use, we need the following information:

- AVG = Average daily demand faced by the distributor
- STD = Standard deviation of daily demand faced by the distributor
- L = Replenishment lead time from the supplier to the distributor in days
- h = Cost of holding one unit of the product for one day at the distributor
- α = service level. This implies that the probability of stocking out is $1 - \alpha$

For the continuous review model, it is frequently used what is known as (Q, R) policy, which basically describes that whenever inventory level falls to a reorder level R, an order for Q units needs to be placed. The purpose of this model is to determine whether the value of these two parameters is, in addition to other relevant values, such as the safety stock level and the average inventory level.

Before starting to compute these parameters, it is necessary to assign values to each of the variables mentioned above:

- AVG = 556 panels/day (calculated from the 16,666 panels/month).
- STD = 50 panels/day. It is a common standard deviation that considers that around 68% portion of the data will fall within the range of 506 to 606 panels/day. This rule, known as the 68-95-99 rule, states that 68% of the population is within 1 standard deviation of the mean.
- L = 90 days. For the most typical PV panel that the company orders, the average supplier lead time is 90 days.
- h = 0.15$/panel x day. The cost of holding one unit of the product for one day at the distributor must include the state, property taxes for holding that product, the maintenance costs, obsolescence costs, and opportunity costs. This cost has been calculated as follows:

Table 14. Calculation of holding costs.

Type of cost	**Concept**	**Daily cost per panel [$/panel x day]**
State taxes, property taxes and insurance	2% of PV panel value	0.02
Maintenance costs	20$/PV panel	0.05
Obsolescence costs	30 years of lifespan, linear amortization over PV panel value	0.03
Opportunity costs	5% of PV panel value	0.05
TOTAL		**0.15**

- α = 0.95. With this value of service level, we would assume that 95% of orders are delivered on time.

Once all the data has been gathered, the main parameters can be calculated:

Safety stock

Safety stock level aims to be essential for any distribution or manufacturing company, as it provides a clear value for inventory that must never be trespassed. According to the continuous review policy, safety stock level can be calculated as follows:

$$Safety\ stock = z \times STD \times \sqrt{L}$$

Equation 8. Formula for computing Safety stock.

The parameter Z is related to the service level that was mentioned before. According to table 13, a service level of 95% corresponds to a z equal to 1.65.

Service level	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%	99.9%
z	1.29	1.34	1.41	1.48	1.56	1.65	1.75	1.88	2.05	2.33	3.08

Figure 19. Relation between parameter Z and service level.

Taking into consideration this, we can compute the total value for the safety stock level:

$$Safety\ stock = 1.65 \times 50\ panels \times \sqrt{90\ days} = 783\ panels$$

Equation 9. Calculation of Safety stock.

Reorder level – R

The reorder level R is the quantity of inventory that indicates when a new order needs to be done. It is calculated as a combination of the safety stock plus the average demand during the lead time:

$$R = Safety\ stock + L \times AVG$$

Equation 10. Formula for computing Reorder Level.

Computing the safety stock value and the suppliers Lead time with the average demand faced by Continental Energy we obtain the following:

$$R = 783\ panels + 90\ days \times 556\,\frac{panels}{day} = 50{,}823\ panels$$

Equation 11. Calculation of Reorder Level.

Order size – Q

After calculating the reorder level R, the next step is to compute the size of the order that will be done (Q):

$$Q = \sqrt{\frac{2 \times k \times AVG}{h}}$$

Equation 12. Formula for computing order size Q.

In this scenario, the variable "k" represents the fixed cost that Continental Energy incurs with each order placement. Based on the information provided in the Network Planning improvement section, a significant portion of the fixed costs associated with ordering is attributed to railroad transportation. To simplify the calculation of these costs, we will assume that 20% of the total railroad transportation costs can be allocated as fixed costs, while the remaining 80% is variable and dependent on the quantity of panels ordered. Given that the overall railroad transportation costs were $50,450 per month, it implies that $10,090 would be designated as fixed costs. Considering that Continental Energy typically places between 10 and 12 orders per month, we can derive a general formula to estimate the fixed costs per order:

$$k = \frac{\text{Monthly fixed costs}}{Monthly\ orders} = \frac{\$50{,}450.40/month}{11\ orders/month} = 4{,}587\$/order$$

Equation 13. Formula for computing parameter k.

With the value of k is now possible to calculate the value of Q, which will provide us with the optimal number of panels that Continental Energy should use when trespassing level R.

$$Q = \sqrt{\frac{2 \times \frac{4{,}587\ \$}{order} \times 556\ panels/day}{0.15\ \$/panel \times day}} = 5{,}832\ panels/order$$

Equation 14. Calculation of order size Q.

Average inventory level

To compute the last parameter of our interest we just need to combine the values of the safety stock plus half the size of the optimized order:

$$Avg\ Inventory\ level = \frac{Q}{2} + Safety\ stock$$

Equation 15. Formula for computing Average inventory level.

$$Avg\ Inventory\ level = \frac{5{,}832\ panels}{2} + 783\ panels = 3{,}699\ panels$$

Equation 16. Calculation of Average inventory level.

In conclusion, through the application of continuous inventory review principles, we have successfully computed several key values that can enhance the existing system. The determination of the reorder level, denoted as "R," enables Continental Energy to establish a threshold at which replenishment is triggered, ensuring a continuous supply of panels. Additionally, the optimal ordering quantity, referred to as "Q," has been calculated, providing guidance on the ideal number of units to order each time to balance inventory costs and meet customer demand. Furthermore, by considering factors such as lead time, demand variability, and desired service level, we have derived the average inventory level and safety stock. These metrics aid in maintaining adequate stock levels to fulfill customer orders while mitigating the risk of stockouts. Overall, these computed values contribute to the improvement of the existing system by promoting efficient inventory management practices, ensuring uninterrupted operations, and optimizing the balance between inventory costs and customer service levels. A summary of the values computed can be observed in table 13:

Table 15. Calculation of Inventory Management parameters.

Parameter	**Value**	**Units**
Safety Stock	783	panels
R - Reorder Level	50,823	panels
Q - Order Quantity	5,832	panels/order
Average Inventory Level	3,699	panels

4.1.3 Supply Contracts

To conclude the solutions chapter aimed at addressing disruptions in Continental Energy's PV panels supply chain, we turn our attention to a different perspective: supply contracts. While we have discussed various solutions related to network planning and inventory management, it is important to consider the role of supply contracts in ensuring a robust and reliable supply chain.

Supply contracts play a crucial role in establishing clear expectations, responsibilities, and commitments between Continental Energy and its suppliers. These contracts can include provisions for quality standards, delivery schedules, pricing agreements, and contingency plans for unforeseen events. By establishing strong and mutually beneficial supply contracts, Continental Energy can enhance its supply chain resilience and mitigate potential disruptions. Key aspects to consider in supply contracts include setting clear performance indicators, such as on-time delivery rates, product quality standards, and response times for resolving issues. In addition, contingency provisions can be included to address scenarios such as supplier failures, natural disasters, or geopolitical disruptions. These provisions can outline alternative sourcing options, stockpiling strategies, or collaboration with backup suppliers.

Furthermore, supply contracts should foster open communication channels and collaboration between Continental Energy and its suppliers. Regular performance reviews, joint forecasting exercises, and shared risk assessment can help build strong relationships and enable proactive problem-solving. These collaborative efforts contribute to a more responsive and agile supply chain, allowing both parties to address potential disruptions swiftly and effectively.

Typically, a buying-selling process requires a two-stage sequential supply chain. On the one side, there should be the buyer’s activities:

- Generating a forecast
- Determining how many units to order from a supplier.
- Placing an order to the supplier to optimize buyer’s own profit.
- Purchase based on forecast of customer demand.

On the other side there is the seller’s activities:

- Reacting to the order placed by the buyer.

Once these stages have been completed, the process will be finished. This is what is called sequential planning (or non-collaborative) supply chain. Some of the main characteristics of this kind of sourcing strategies include:

- The buyer assumes all the financial risk of having more inventory than sales.
- The buyer limits his order quantity because of the huge financial risk. Since the buyer limits his order quantity, there is a significant increase in the likelihood of running out of stock.

- The seller would like the buyer to order as much as possible.
- The seller takes no risk.

If the seller shares some of the risk with the buyer, it may be profitable for the buyer to order more:

- Reducing the out-of-stock probability
- Increasing profit for both the seller and the buyer.

In sequential planning (emphasis is on efficiency) each stage of the supply chain optimizes its profit with no regard to the impact of its decisions on the other supply chain entities whereas in global supply optimization (emphasis is on both efficiency and effectiveness), the objective is to coordinate supply chain activities and collaborate with others so as to maximize supply chain performance. Since supply contracts enable risk sharing to maximize supply chain performance, in essence they facilitate global supply optimization.

There are two main approaches to supply contracts that could lead Continental Energy to enhance their relationship with their PV panels suppliers: MTO and MTS:

- Make-to-Order (MTO): In an MTO approach, products or components are manufactured or produced based on specific customer orders or project requirements. Production does not occur until an order is received. This approach allows for customization and flexibility to meet individual customer needs. MTO contracts are often used when products have unique specifications, varying configurations, or when demand is uncertain. The advantage of MTO is that it reduces the risk of excess inventory but may have longer lead times due to production starting after order placement.
- Make-to-Stock (MTS): In contrast, the MTS approach involves producing goods or components based on forecasted demand and stockpiling them in anticipation of customer orders. In this approach, products are manufactured and stored in inventory before customer orders are received. MTS contracts are suitable when demand is more predictable, products have standardized specifications, or when there is a need for quick order fulfillment. MTS enables faster lead times as products are readily available for delivery, but it carries the risk of overstocking and potentially incurring higher holding costs.

The choice between MTO and MTS contracts depends on factors such as the level of customization required, demand variability, lead time considerations, and the company's ability to manage inventory effectively. Each approach has its advantages and challenges, and the appropriate choice depends on the specific characteristics and goals of the business. Considering that Continental Energy manages and installs solar PV panels, it is likely that their operations involve a certain level of customization to meet specific project requirements. In this case, a Make-to-Order (MTO) supply contract may be more suitable. MTO contracts allow for flexibility in accommodating customer specifications and variations in PV panel configurations. As a result, Continental Energy can provide tailored solutions that align closely with customer needs.

Furthermore, the solar PV industry experiences demand variability due to factors such as project timelines, market trends, and regional variations. This variability may make accurate demand forecasting challenging. By adopting an MTO approach, Continental Energy can avoid the risk of overstocking and reduce holding costs associated with maintaining excess inventory. Instead, panels are produced based on confirmed orders, reducing the likelihood of obsolete inventory.

However, it's important to note that MTO contracts often have longer lead times compared to Make-to-Stock (MTS) contracts. Continental Energy should assess their ability to manage lead times effectively and ensure timely coordination with suppliers to meet project timelines.

Some types of contracts that Continental Energy should propose to their suppliers are the following:

Buy-back Contract

In this contract, the seller agrees to buy back unsold goods from the buyer for some agreed-upon price higher than what is called the salvage value. The salvage value is the estimated resale value of an asset at the end of its useful life. Under this contract, the buyer has an incentive to order more:

- As the seller’s risk increases, there is usually also an increase in the buyer’s order quantity.
- It decreases the likelihood of running out-of-stock.
- Compensates the seller for the higher risk.

Revenue Sharing Contract

Under a revenue sharing contract, a buyer pays a seller a wholesale price for each unit purchased plus a percentage of the revenue the buyer generates. Under this contract, the buyer transfers a portion of the revenue from each unit sold to the end customer, back to the seller or the manufacturer. This kind of contracts have the following characteristics:

- Requires a seller to monitor the buyer's revenue and this increases administrative cost.
- Buyers have an incentive to push competing products with higher profit margins, because of the revenue sharing.
- These types of contracts reduce the buyer's margin as part of the revenue is transferred back to the seller.

Quantity-Flexible Contracts

Under this contract, the seller provides full refund for returned (unsold) items as long as the number of returns is no larger than a pre-agreed quantity. Some of its main characteristics include:

- It gives a full refund for a portion of the returned items, whereas the buy-back contract provides a partial refund for all returned items.
- Opportunities: commonly used by several major manufacturers, particularly in the computer industry where demand uncertainties, price fluctuations, and dependence on parts suppliers are common.
- Challenges: extra transportation, and restocking costs for returned/unsold items.

Sales Rebate Contract

Sales rebate contracts provide a direct incentive to the retailer to increase sales by means of a rebate paid by the supplier for any item sold above a certain quantity. This contract can include different parameters:

- It could be over the total-spend.
- A specific number of units.
- Purchasing a collection or family of products.
- A marketing objective such as a published referral.

In conclusion, the selection of the most suitable contract type for Continental Energy, among the options of Make-to-Order (MTO) contracts, including Sales Rebate Contracts, Quantity-Flexible Contracts, Revenue Sharing Contracts, and Buy-Back Contracts, will depend on their specific relationships with suppliers. Each of these contract types offers distinct advantages and considerations within the MTO framework.

Sales Rebate Contracts can be a great option when suppliers are willing to provide incentives based on achieved sales volumes, fostering a mutually beneficial relationship between Continental Energy and its suppliers. Quantity-Flexible Contracts provide the flexibility to adjust order quantities, enabling Continental Energy to adapt to fluctuating market demands or uncertain conditions. Revenue Sharing Contracts can align incentives and establish a partnership approach with suppliers, where risks and rewards are shared based on sales performance. This collaborative model promotes shared success and encourages both parties to work towards common goals. Furthermore, the Buy-Back Contract can offer Continental Energy flexibility in managing inventory, mitigating potential stockouts or excess inventory situations. This arrangement allows unsold inventory to be sold back to the supplier, reducing the risk of holding obsolete stock and promoting efficient inventory management practices.

The selection of the most appropriate contract type within the MTO context will depend on Continental Energy's specific requirements, supplier relationships, and strategic objectives. It is essential for Continental Energy to evaluate these factors and collaborate closely with their suppliers to determine the most beneficial contract type that aligns with their business goals and enhances their supply chain operations.

CHAPTER 5
IMPACT OF THE IMPROVEMENTS

In this chapter, we delve into the economic and environmental implications of implementing the proposed solutions to address disruptions in the solar electric supply chain. Building upon the previous chapters, which focused on network planning, inventory management, and supply contracts, we now turn our attention to assessing the broader impacts of these strategies. By analyzing the economic considerations, such as cost savings, efficiency improvements, and customer satisfaction, we can gauge the financial benefits of the implemented solutions. Additionally, we explore the environmental benefits, such as reduced carbon emissions, resource conservation, and sustainability gains, which align with the renewable energy nature of the solar electric industry. This chapter aims to provide a comprehensive evaluation of the general impact of the proposed solutions, emphasizing the synergies between economic prosperity and environmental stewardship in the solar electric supply chain.

5.1 Economic Impact

Evaluating the economic impact of engineering projects requires careful consideration of various tools and methodologies that can effectively assess the key economic parameters. It is crucial to adapt the evaluation approach to each specific project and identify the most relevant parameters for analysis. For the current case, the main economic indicators chosen for assessing the improvements are Cost Savings and Return on Investment (ROI). These indicators provide valuable insights into the financial benefits gained from the implemented enhancements and help gauge the project's overall economic viability.

Costs Savings

Cost savings play a crucial role in evaluating the economic impact of improvements made to the solar electric supply chain. In this project, significant cost savings can be attributed to the network planning improvements, which have optimized transportation routes and reduced transportation distances. However, it's important to note that to obtain the complete picture of cost savings, consideration must also be given to the impact of supply contracts and inventory optimization. While the network planning improvements contribute to tangible savings, the overall cost savings should also account for the potential benefits resulting from optimized supply contracts and inventory management. Unfortunately, due to the lack of current data on Continental Energy's inventory policies, it has been challenging to quantify the specific monetary savings resulting from these factors. However, by considering the combined impact of network planning, supply contracts, and inventory optimization, it is reasonable to anticipate significant cost savings for the company, positively impacting their bottom line and enhancing overall profitability. Due to this, the only tangible cost savings that have been determined for the company are the ones corresponding to the following table:

Table 11. Comparison between monthly expenses of new and existing transportation networks.

Network distribution	PV panels' transportation mode	Itemized monthly expenses [$/month]	Total monthly expenses [$/month]
Existing system	Railcar	$ 50,450.40	$ 77,878.71
	Full Truckload	$ 27,428.31	
New system	Railcar	$ 37,796.85	$ 51,176.36
	Full Truckload	$ 9,792.51	
	Warehouse	$ 3,587.00	

The cost savings amount a total of approximately $26,702.35 per month, which represents a total of 34.28% reduction in monthly expenses for PV transportation. Savings of $320,428 can be extrapolated to each year.

Return On Investment

ROI stands for Return on Investment, and it is a financial metric used to evaluate the profitability and efficiency of an investment. ROI measures the return or gain generated from an investment relative to its cost. It is expressed as a percentage and provides insights into the financial performance and profitability of a project or investment. To calculate ROI, it is generally used the following formula:

$$ROI = \frac{Net\ Profit}{Investment\ Cost} \times 100\% = \frac{Financial\ Benefits - Investment\ Cost}{Investment\ Cost} \times 100\%$$

Equation 17. Formula of Return On Investment.

For the current case, the financial benefits considered will be the cost savings mentioned above, while the investment cost will be determined by the budget of the project, which was specified at the beginning of the project, and amounted a total of \$10,272 (equivalent to 540 Credit Hours) plus the honorary of my work. The initial budget included the assessment, review and experience from my advisor and university facilities. The part of the honorary has been calculated as 540 hours of engineering work per an average price per hour for engineers with master's level of education (\$43/hour), resulting in a total price of \$23,220. Adding both terms we obtain a total investment cost of \$33,492. Additionally, we would need to consider the horizon of the project and the financial benefits, which has been determined to be 2 months due to the due to the ease of applying the improvements. Accordingly, the financial benefits for 2 months would be the multiplication of \$26,702.35 per 2, resulting in \$53,404.7.

Computing both terms, we can obtain the total ROI, generally expressed in percentage:

$$ROI = \frac{\$53{,}404.7 - \$33{,}492}{\$33{,}492} \times 100\% = 59.46\%$$

Equation 18. Calculation of Return On Investment.

Common values for ROI's engineering projects could be between 20-40%, which means that this project provides a high ROI percentage if compared to standard projects. A high value of ROI typically indicates a more favorable investment performance, as it suggests that the returns generated significantly exceed the initial investment cost. A high ROI implies that the investment has been successful in generating substantial profits relative to the amount invested.

5.2 Environmental Impact

In this section, we delve into the environmental impact assessment of Continental Energy's solar electric supply chain project using the MET (Materials, Energy, Toxicity) matrix methodology. As sustainability becomes an increasingly vital consideration, it is crucial to understand the ecological consequences of our actions. The MET matrix provides a systematic framework for evaluating the project's environmental footprint across key dimensions, namely materials, energy, and toxicity. By analyzing the materials used, energy consumption, and potential toxic elements within the supply chain, we can gain valuable insights into the project's environmental impact. This methodology enables us to identify areas for improvement, make informed decisions, and promote responsible practices that align with Continental Energy's commitment to sustainability.

The MET matrix is a qualitative tool that takes the form of a 3x3 matrix with descriptive text in each of its cells. One dimension of the matrix is composed of a qualitative input-output model that examines environmental concerns related to the product's materials use, energy use, and toxicity. The other dimension looks at the life cycle of the product through its production, use, and disposal phase.

A possible assessment of the impact of the improvements including network planning, inventory management, and supply contracts on the MET (Materials, Energy, Toxicity) matrix for Continental Energy's solar electric supply chain project:

Materials

- Network Planning: The optimization of transportation routes and consolidation strategies have reduced the distance traveled and minimized the use of packaging materials. This has led to a reduction in resource consumption and waste generation, positively impacting the environmental sustainability of the materials used in the supply chain.
- Inventory Management: Improved inventory management practices, such as reducing excess inventory levels and implementing just-in-time principles, have reduced the overall material requirements and waste associated with inventory holding. This has contributed to resource conservation and minimized the environmental impact related to materials.

Energy

- Network Planning: By optimizing transportation routes, the improvements in network planning have reduced the overall energy consumption associated with the movement of PV panels. The consolidation strategies and efficient load planning have led to fuel savings and a decreased carbon footprint, contributing to energy conservation.
- Supply Contracts: The implementation of supply contracts, such as quantity-flexible contracts and revenue-sharing contracts, would enable Continental Energy to achieve better coordination with suppliers. This will result in reduced lead times and transportation distances, leading to energy savings and a more efficient use of resources.

Toxicity

- Network Planning: The optimization of transportation routes and consolidation strategies have minimized the need for additional handling and intermediate storage, reducing the risk of mishandling or accidental spills of potentially toxic substances.

- Supply Contracts: The use of supply contracts that prioritize environmentally friendly practices has ensured the selection of suppliers that adhere to strict regulations and guidelines regarding the use of toxic substances. This has helped minimize the potential environmental and health risks associated with hazardous materials.

Evaluation

The improvements in network planning, inventory management, and supply contracts have had a positive impact on the MET matrix. They have contributed to reduced resource consumption, minimized waste generation, and enhanced energy efficiency throughout the supply chain. By optimizing transportation routes, reducing excess inventory, and promoting environmentally friendly practices through supply contracts, Continental Energy would successfully improve the sustainability of their materials, reduced energy consumption, and minimized potential toxic risks.

CHAPTER 6

CONCLUSIONS

The project has yielded significant and tangible results in terms of cost reduction and lead time improvement within the solar electric supply chain of Continental Energy. By analyzing the data and implementing targeted improvements, the following conclusions can be drawn:

Cost reduction

The project has successfully achieved the objective of reducing costs by at least 20%. Through the implementation of network planning improvements, such as optimized transportation routes and strategic warehouse placements, a total of 34.28% costs savings have been achieved. Additionally, the enhancements in inventory management and supply contracts have contributed to cost reduction by improving efficiency and minimizing unnecessary expenses. The achieved cost reduction not only strengthens the financial position of Continental Energy but also enhances its competitiveness in the market.

Lead Time Improvement

The project has successfully met the objective of reducing lead time by at least 1%. By implementing inventory optimization techniques, ensuring timely availability of PV panels, and establishing efficient supply contracts, the lead time from order placement to delivery has been significantly reduced. With the network planning implementation, an improvement of 1.84% of Lead Time reduction can be successfully achieved. This improvement would positively impact customer satisfaction, allowing Continental Energy to deliver projects more efficiently and meet client expectations in a timely manner.

Enhanced Financial Performance

The cost reduction achieved through improved network planning, inventory management, and supply contracts has had a direct impact on the financial performance of Continental Energy. The savings generated from streamlined logistics operations, reduced transportation distances, and optimized inventory levels have resulted in improved profitability. These cost savings can be reinvested in further business growth, research and development, and other strategic initiatives.

Competitive Advantage

The successful implementation of the project's objectives has positioned Continental Energy with a competitive advantage in the solar electric supply chain industry. The company's ability to offer cost-effective solutions, shorter lead times, and improved customer service gives it an edge over competitors. The project's outcomes have solidified Continental Energy's reputation as an efficient and reliable provider of solar PV panels, attracting more customers and strengthening its market position.

In conclusion, the project's efforts to reduce costs by at least 20% and improve lead time by at least 1% have been highly successful. The achieved cost savings, improved efficiency, and enhanced customer satisfaction highlight the project's positive impact on Continental Energy's economic performance. From my point of view, by embracing these improvements, the company is well-positioned for continued growth and success in the dynamic solar electric supply chain industry.

Personal thoughts

Throughout this project, I have gained valuable insights and reflections. Here are some key points that capture my personal thoughts:

- Collaboration: Working closely with the team at Continental Energy and other stakeholders highlighted the power of collaboration. By leveraging diverse perspectives and expertise, we were able to achieve impactful solutions.
- Continuous Improvement: The project emphasized the importance of continuously striving for improvement. By analyzing data, identifying areas for enhancement, and implementing innovative solutions, Continental Energy achieved significant cost savings and operational efficiency.
- Environmental Responsibility: The project's focus on assessing the environmental impact reinforced the importance of sustainable practices in the renewable energy sector. By considering factors like emissions and lifecycle impact, we contributed to a greener future.
- Business Impact: The project demonstrated that strategic improvements in network planning, inventory management, and supply contracts can have a profound impact on business success. By reducing costs, improving customer satisfaction, and strengthening competitiveness, Continental Energy positioned itself for growth.

- Continuous Learning: Engaging in this project expanded my knowledge and passion for supply chain management and renewable energy. It was a valuable learning experience, allowing me to contribute to real-world challenges and drive positive change.

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