A Sustainable Supply Chain for a Coal Power Plant

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Sustainability in Supply Chains and Operations

Abstract

The sustainable supply chain proposed in this paper aims to study the operational process of a coal-fired power plant, to see how a humble fossil transforms into energy, and how electricity is created step by step inside the plant. In order to fully understand the eco-design of this supply chain network, we have studied the utilization of electrostatic precipitators in a coal power plant, and their ability to remove ash, dust and smoke from the flue gas so it does not pass into the atmosphere, thus comply with environmental regulations.

Keywords
Sustainable supply chain, coal power plant, eco-design, electrostatic precipitators, environmental regulations.

1. Introduction

When we meet the needs of the present without compromising the ability of future generations to meet their own needs, that is exactly how we define Sustainable Development, this term has been defined in many ways, and it can be interpreted in different ways, due to its huge impact on our social, environmental and economic life, therefore the concept of green supply chain or the eco-design of supply chain have attracted a growing interest over the recent decade, as a result designing a green supply chain is becoming increasingly critical and very important.

In fact, the prime concern of designing a green supply chain is the management process of placing appropriate logistic green infrastructures, and maintaining the profitability and prosperity of such business, therefore sustainability is becoming an imperative for manufacturing industries, and it is attracting increasing interest from both academia and industry.

In the first place, we suggest to begin our contribution with a study about designing a sustainable supply chain, which is one of the crucial planning problems in supply chain eco-design; meanwhile companies have to obey certain environmental regulations and several indicators of the environmental performance for that reason it is fundamental

to design green supply chains, as we have noticed in the last years, a major number of supporting publications and relevant studies have flashed the lights on this issue.

The rest of this paper is dedicated to the operational process of coal-fired power plants, the advantages and disadvantages of using coal as a source for producing electricity, and then we will proceed to study the use of electrostatic precipitators in this type of plants in order to reduce the percentage of the chemical toxic outputs, how they function inside the plant and how they can make an eco-friendly change for the image that has been labeling coal power plants for decades.

2. Designing a Sustainable Supply Chain

For years the producers' responsibilities were finished when the product was on the shelves in the shop or when the guarantee period was over. Supply chain management was perceived as the planning and control of the flow of goods from the sourcing base to the final consumers, accompanied with the necessary information and money for the independent entities along that chain. Now we are looking into a different era, where firms are embedding sustainability upfront in the design of a company's supply chain network (Rezaee et Al. 2015), it is an important strategic choice, which indicates that the sustainability factor plays a key role for the long-term resilience of a supply chain network.

The current paper is based on the Google Scholar and Scopus library databases, and it covers the major journals in the supply chain area over the last years. Designing a sustainable supply chain network is a critical factor in reducing the costs, improving service level, and responding to environmental issues, the environmental performance of a supply chain is actually assessed by suitable measures, in fact there are three ingredients relevant to supply chain that affect environmental impact: product design, facilities and transport.

The interest in environmentally friendly supply chain management has been raised considerably in the recent decades; this can be seen by the number of initiatives taken by companies. Firms and plants are often perceived to be responsible for environmental problems in the entire supply chain from the sourcing base to end-of-life recovery issues, it is expected that the manufacturers will reduce the sources of waste throughout their entire supply chains, across multiple entities, upstream and downstream (suppliers, distributors and consumers).

A sustainable supply chain network connects with partners who should make managerial decisions with regard to environmental consequences (Abdallah. T et Al. 2012); it enhances competitiveness and creates better customer service, resilience and increased profitability, these managerial strategic decisions consist of determining locations and number of facilities, capacities and sizes of facilities, technology and area allocation for production and process of products at different facilities, selection of suppliers, and so on.
The environmental issues related to supply chain design concern the raw materials used to produce the products, the selection of suppliers, the facilities, the manufactories and the plants (either owned by the firm or by subcontractors), the plant departments, the equipment and labor capacities, the downstream concerned parties such as the distribution centers, the retail outlets or the consumers, the variety of ways of transportation, the storage areas and stock methods.

To satisfy customer demand, while optimizing long-term sustainability (low cost / high performance), the design of the supply chain network is asked to make the following strategic decisions while considering economic, environmental and social aspects:

(1) Where to establish manufacturing plants and distribution centers? What capacity? Should existing facilities be expanded?

(2) Which existing and new plants should be used per time period? At what level?

(3) Which suppliers should be selected? Should we consider alternative ones as well?

(4) What is the appropriate labor level at each owned plant? At each distribution center?
(5) Which are the suitable manufacturing and logistics subcontractors to collaborate?
(6) Which transportation modes should be utilized? And at what level?
(7) Which transportation routes should be followed?

Companies are forced to adopt ecologically responsive practices to meet legislative requirements but they can also benefit from the green behavior (Mota. B et Al. 2015). For example, building the technological and organizational capacity to collect, recycle and reuse waste or returns stream can enhance the availability of materials as well as clear up the supply channels. There are more than two thousand identified factor of environmental performance in supply chain, but as studies have showed only three indicators are the typical ones, these three critical metrics are: the quantity of Greenhouse Gas Emissions, Energy consumption, and the quantity of Waste generated. **Table 1** explains how each of these factors provides a firm basis for future targets, and how it is calculated based on the type of data.

The main criteria used in selecting the appropriate indicators are environmental relevance, international comparability, and applicability of the information provided by the indicator. The environmental indicators should:

- Provide a representative picture of environmental conditions and pressures on the environment
- Be simple and easy to interpret
- Be based on international standards and provide a basis for international comparison
- Be adequately documented and of known quality
- Be updated at regular intervals in accordance to reliable procedures

Table 1. Indicators of the environmental performance

Environ. Indicator	**Absolute Data**	**Normalized Data**	**Trend Data**
GHG Emission	Total Annual Carbon Dioxide Emissions	Carbon Dioxide emissions per employee, per unit of output, etc.	Total emissions of Carbon Dioxide or emissions per employee compared with previous years.
Energy consumption	Total annual Energy (water, air, temperature, pressure) consumption	Energy consumption per employee, per unit of output, etc.	Total Energy consumption or consumption per employee compared with previous years
Waste output	Total annual waste output in tons.	Waste output per employee, or per unit of output, etc.	Total waste or waste per employee compared with previous years.

The readers of the environmental report should get a clear and meaningful picture of the organization's environmental performance. To do this, a range of data types are involved, including:

a) Absolute data - information on performance is usually collected in terms of absolute units of measurement (e.g. tons, cubic meters, gigajoules, etc.) over a given period of time.

b) Trend data - data per annum presented over a number of years (e.g. total waste to landfill for each year from 1997-2000) helps show performance trends.

c) Normalized data - makes relationships between figures visible, by relating two absolute figures to each other (e.g. cubic meters of water used per employee, the proportion of recycled waste to total waste, and total CO2 emissions per unit of output, etc.)

Over time, generally between three and five years, when a company has been influenced by the managerial decisions, many parameters, including demand, capacity and costs of the supply chain network, can have major fluctuations. The parameters associated with sustainable supply chain network design involve a huge volume of data, often giving wrong estimations and doubtable results due to inaccurate forecasts or poor measurements in the modeling process; hence the supply chain network eco-design has been under uncertainty and obtained significant and sensitive attention in practice and academia as well (Bertrand Baud-Lavigne et Al. 2017).

3. The Supply Chain inside a Coal Power Plant

Coal is one of the most affordable and largest domestically produced sources of energy in the world. It is used to generate a substantial amount of our electricity – about 57%. The challenge is to find ways to burn it more sustainably.

Historically, a wide variety of environmental impacts are associated with generating electricity from coal, because the same rich chemical composition making coal a valuable energy resource is also responsible for creating byproducts, these include nitrogen oxide and sulfur dioxides.

3.1 Operational Process of Coal-fired Power Plant

The question, 'How does a coal power plant work?' can be answered at many levels. Fundamentally a coal fired power plant converts the chemical energy in coal to heat, converts the heat to mechanical energy, and uses the mechanical energy to rotate a generator and convert it to electrical energy (Harlan Bengtso, 2010).

Coal power plants and gas or oil fired power plants burn a fuel to generate heat. A nuclear power plant carries out a controlled nuclear reaction that generates heat and a solar thermoelectric power plant uses solar radiation to heat a fluid. In all of these thermoelectric power plants, the heat is used to heat water and generate steam that is then passed through a steam turbine, making it rotate and drive an electrical generator. Thus a thermoelectric power plant converts the energy in coal, gas, oil, nuclear fuel, or the sun's rays into electrical energy.

The conversion from coal to electricity takes place in three stages. **Figure 1** is a plain model of the main units of a coal-fired power plant.
Stage 1: the first conversion of energy takes place in the boiler. Coal is burnt in the boiler furnace to produce heat. Carbon in the coal and Oxygen in the air combine to produce Carbon Dioxide and heat.
Stage 2: which is the thermodynamic process, and it proceeds like follow:

a. The heat from combustion of the coal boils water in the boiler to produce steam. In modern power plant, boilers produce steam at a high pressure and temperature.
b. The steam is then piped to a turbine.
c. The high pressure steam impinges and expands across a number of sets of blades in the turbine.
d. The impulse and the thrust created rotates the turbine.
e. The steam is then condensed and pumped back into the boiler to repeat the cycle.

Stage 3: in the third stage, rotation of the turbine rotates the generator rotor to produce electricity based of Faraday's Principle of electromagnetic induction.

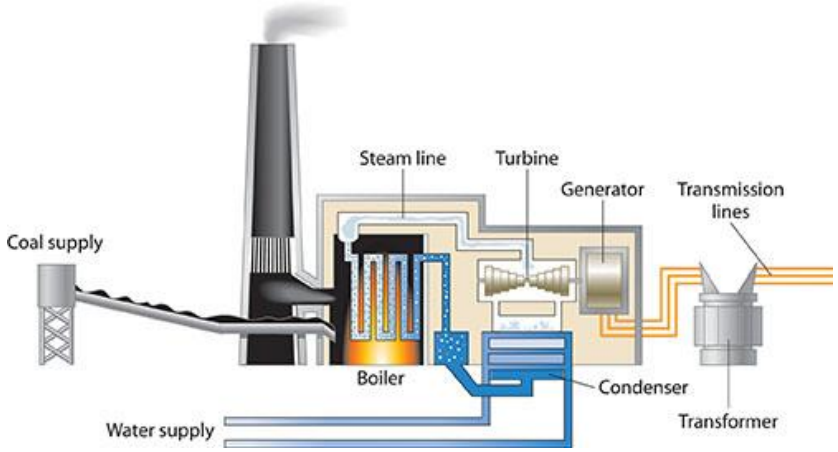

Figure 1. Main units of a coal-fired power plant

In practice to effect these three stages of conversion, many systems and sub systems have to be in service. Also involved are different technologies, like combustion, aerodynamics, heat transfer, thermodynamics, pollution control, and logistics.

3.2. Advantages and disadvantages of coal energy

There are many advantages and disadvantages of using coal energy to produce electricity. Its advantages and disadvantages are the following:

Advantages of using coal to produce electricity:

- Coal energy is an affordable energy source because of the coal's stable price compared to other fuel sources
- Coal is easy to burn
- Coal produces high energy upon combustion
- Coal energy is inexpensive
- Coal is abundant
- Coal energy is a reliable energy source

Disadvantages of using coal to produce electricity:

- Coal energy produces large amount of carbon dioxide which leads to global warming and climate change
- The burning of coal is not environmental friendly because it produces harmful byproducts and gas emissions such as sulfur dioxide, carbon dioxide and nitrogen oxide that causes pollution to the environment including acid rain
- Coal energy is nonrenewable energy source
- Coal is fast depleting because we consume too much of it
- Coal mining ruins the environment and puts the lives of people specially the coal miners in danger

We cannot deny the fact that using coal energy is very important to us. All of us want an affordable and reliable energy source which we can only get by using coal energy. Although using coal energy is very significant for us and living without it would become impossible, we should always open our minds to the damage the continuous use of coal energy will eventually bring to us and to our environment, that is the reason why most plants are now installing electrostatic precipitators units and flue gas desulfurization systems in order to reduce the quantity of the harmful outputs of the power plant.

4. Use of Electrostatic Precipitators (ESP) in Coal Power Plant

The electrostatic precipitators (ESP) are extensively used in the thermal power plant or coal/steam power plant for removal of fly ash from the electric utility boiler emissions. The use of electrostatic precipitators is growing rapidly because of the new strict air code and environmental laws. Electrostatic precipitators can be designed to operate at any desired efficiency for use as primary collector or a supplementary unit to cyclone collector (A. Jaworek et Al. 2014). It is often considered worthwhile to retain an existing cyclone collector as primary collector in the case where the fly-ash collection efficiencies must be upgraded especially where there is a large amount of un-burnt carbon in the fly-ash. Actually it is because the presence of large quantities of the carbon in the gas can adversely affect the efficiency of the electrostatic precipitator can be adversely affected. As you can see in **Figure 2** ESP unit has been installed in a coal-fired power plant.

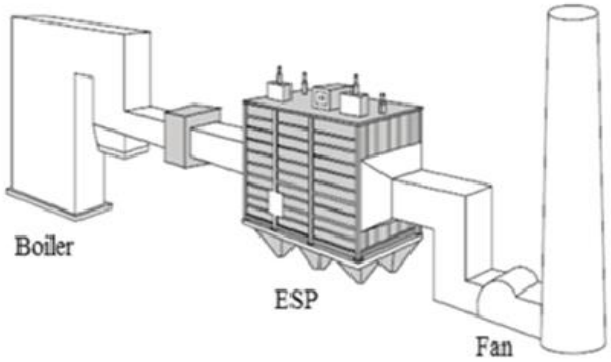

Figure 2. Placement of ESP unit in a coal-fired power plant

4.1. Operational process of Electrostatic Precipitators

Electrostatic precipitation is an extremely efficient way of filtering fine particles from a flowing gas. Electrostatic precipitators (ESPs) can handle large volumes of air without significantly slowing down the rate of flow, because of the low pressure drop across the electrostatic filter (Heng Shen et Al. 2018). So how does an electrostatic precipitator work?

The dust laden gas is passed between the oppositely charged conductors and is becomes ionized as the voltage applied between the conductors is sufficiently large (30kV to 60kV depending upon the electrodes spacing). As the dust laden gas is passed through the highly charged electrodes, both negative and positive ions are formed (positive ions will be a high as 80%). The operating principle is well illustrated in **Figure 3.**

The ionized gas is further passed through the collecting unit which consists of set of metal plates. Alternate plates are charged and earthed. As the alternate plates are grounded, high intensity electrostatic field exerts a force on the positive charged dust particles and drives them towards the ground plate. The deposited dust particles are removed from the plates by giving the shaking motion of the plates with the help of cams driving by external means (Ming Dong et Al. 2018). The dust removed from the plates with the help of shaking motion is collected in the dust hoppers. Care should be taken that the dust collected in the hopper should not be entrained in the clean gas.

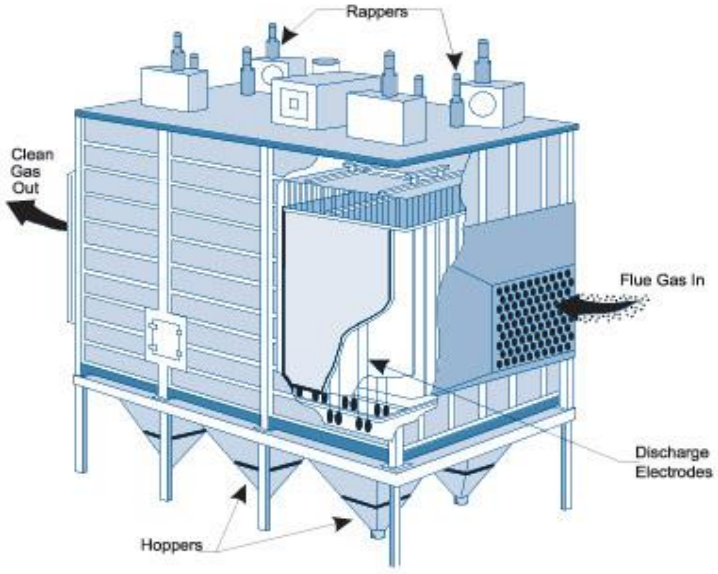

Figure 3. ESP operational process in a power plant

4.2. Effectiveness of Electrostatic Precipitators

Electrostatic precipitators are extremely effective, and are capable of removing more than 99% of particulate matter. Since 1940, emissions of particulate matter smaller than 10 micrometers have been reduced by a factor of 5. However, this high level of effectiveness comes at a high cost - about 2-4% of a power plant's electrical energy output goes into operating electrostatic precipitators and other systems used to remove particulate matter (Fernando Menéndez et Al. 2015).

The small dust particles below 10 micron cannot be removed with the help of mechanical separators. And wet scrubbers cannot be used if sufficient water is not available. Under these circumstances, electrostatic precipitators are very effective.

The effectiveness of a certain precipitator is determined by how well the specific device deals with the unique features and problems of the plant it is used at. Additionally, precipitator effectiveness is also determined by the temperature and moisture content of the flue gas.

In spite of the cost high of electrostatic precipitators, they are widely used in pulverized coal fired thermal power stations for its effectiveness on fine ash particles compared to other methods.

5. Conclusion

In this paper we have presented the design of sustainable supply chain network, the need to adapt an eco-friendly management for all companies and firms, plants are now forced to adopt ecologically responsive practices to meet legislative requirements, however they can also benefit from the green behavior on the long term.

We shaded the light on coal-fired power plants, as an example of a sustainable supply chain; we have studied its operational process to produce electricity, as well as the advantages and the disadvantages of using coal as a source of energy. In order to keep the power plant respectful of the environmental regulations and the ecological standards, units of electrostatic precipitators have been installed.

Which lead us to our last part of this contribution, where we focused on the working principle of electrostatic precipitators their utilization in a coal-fired power plant, and last we have showed their highlighted points of effectiveness.

More than half of the electricity generated in the world is by using coal as the primary fuel, which is why more and more researches are being done in the last three decades, in the interest of making the process of a coal-power plant specifically, and all kinds of power stations generally, less polluting and more sustainable.

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Biographies

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