A LIFE CYCLE ANALYSIS APPROACH FOR MAKING SUSTAINABLE FIBER OPTIC PURCHASING DECISIONS IN THE TELECOMMUNICATION INDUSTRY

by

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ABSTRACT

JESSE AARON STEPHENS: A life cycle analysis approach for making sustainable fiber optic purchasing decisions in the telecommunication industry. (Under the direction of DR. ERTUNGA OZELKAN)

In recent decades, substantial research has surfaced that links global climate change with the human element. As the human species has evolved, the industrialization of prosperous nations has produced extreme consequences on our environment. Continual degradation of our surroundings has proven detrimental to our future. With this in mind, many companies are making progressive steps to become more sustainable (environmentally friendly, socially responsible and economically feasible), telecom providers are also researching ways that they might optimize their network grids in order to achieve greater efficiencies and reduce waste. Although this emergence of sustainable thinking is beneficial to our environment and society, many of these thoughts are coming after potentially dangerous products have already been placed on the open market. Life Cycle Analysis (LCA) is a methodology that aims to map the environmental footprint of any process, product or material by evaluating the impacts of products or materials from the extraction of their raw materials to their eventual disposal. With this information in hand, companies can begin making sound decisions toward the development and production of an eco-friendly socio-responsible product, all while realizing potential cost-cutting opportunities through the use of alternative materials. This paper aims to revise and redirect the current purchasing habits of a major telecom provider by using Analytical Hierarchy Process (AHP) in conjunction with LCA. More specifically, purchasing of the synthetic material alternatives used in the exterior jacketing of fiber optic cables is analyzed to create a more sustainable decision process. The results show that sustainable options can be obtained without sacrificing the traditional cost objective significantly.

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LIST OF ABBREVIATIONS

AHP	Analytical hierarchy process
CI	Consistency index
CR	Consistency ratio
DIA	Dedicated internet access
EPA	Environmental Protection Agency
EPL	Ethernet private line
HDPE	High-Density Polyethylene
ISP	Internet service provider
IT	Information technology
LCA	Life cycle analysis
LDPE	Low Density Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PVC	Polyvinyl Chloride
REACH	Registration, Evaluation, Authorization and Registration of Chemicals
RI	Random index
RoHS	The Restriction of the Use of Certain Hazardous Substances in Electronic Equipment
ROI	Return on investment
STP	Shielded twisted pair
TBL	Triple bottom line

TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impacts
USD	United States Dollar
UV	Ultra Violet

CHAPTER 1: INTRODUCTION

The planning, development and implementation of a sprawling urban city is no easy task. For a moment, consider the modern metropolitan city perhaps in which you may currently reside; at some point, a city planner considered the effects of each additional roadway, neighborhood, shopping plaza or educational campus. The coordination of traffic, whether it be commercial, residential or pedestrian must be painstakingly reviewed and analyzed for efficiency and efficacy. A city planner must debate the location of potential city parks and recreational areas along with the types of plants that reside there. Minute details such as the fabric used on decorative lampposts, or the bulbs used in said lamps, must all be considered as they all have a potential impact on the city and its sustainability. Energy conservation strategies, such as daylighting, shade for natural cooling or wind patterns that may impact each building's envelope are all elements that must be deliberated. Erosion and storm water maintenance can be impacted by proper landscaping, natural vegetation, and irrigation must be considered. Although many residents will pass by these objects without much thought, every element of a developing sustainable city has a purpose and an impact. The same consideration must be applied to the materials that are used in its establishment; especially with regards to its major power and IT networks. This paper takes aim at the potential environmental impacts of materials utilized by the telecommunication industry during the expansion of the geographical network footprint in an expanding city.

Currently there are three standard forms of cabling used in the telecom industry; Shielded Twisted Pair (STP), Coaxial and Fiber Optic. Telecommunication companies utilize a blend of these three forms of cabling to achieve a satisfactory level of service for their clients while remaining cost effective. STP or Ethernet, developed by the Xerox Corporation, is the most basic form of cabling, and has been around for over 40 years ("The History of Network Cabling", 2013.). Every few years an upgraded form of STP is released that allows it to stay up to speed with the emerging demands of newer technology. Currently the standard Ethernet Cable used in most customer facing network solutions past the modem is either Cat5e or Cat6. As illustrated in Figure 1, this cable is comprised of strands of insulated copper wiring twisted around each other, which reduces electrical field interference (Lu, 2012).

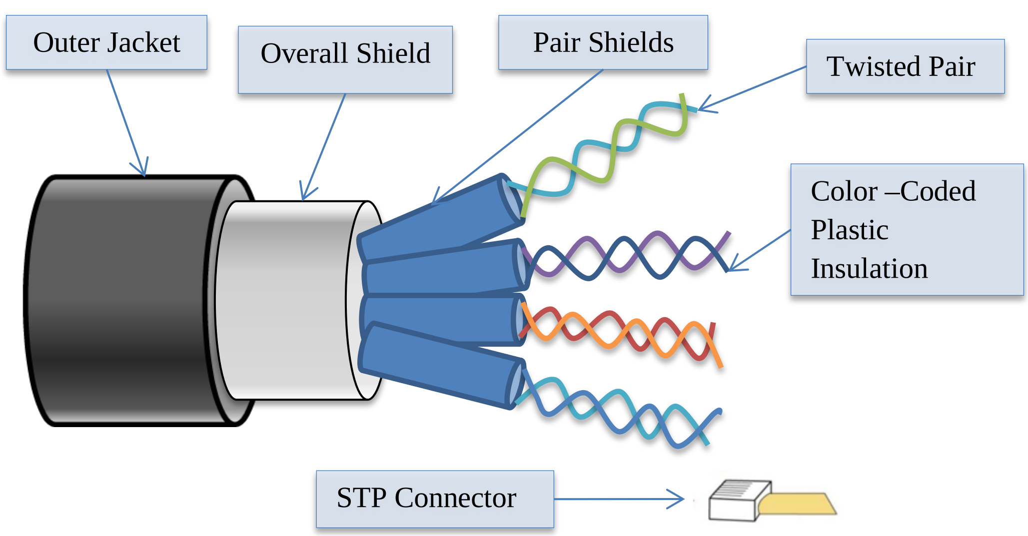


Figure 1: Shielded twisted pair cable (NIKUM NEWA, 2013)

Coaxial cable is the backbone of any interior cabling for standard homes and businesses. Theorized in the late 19th Century, coaxial cable took off after its use in the

Transatlantic Telegraph lines (McElroy, 2001). Known for its rugged sheathing, coaxial cable can withstand a multitude of environmental situations. Although advances have allowed bandwidths to steadily increase since its initial use, the concept of coaxial cable has remained sound. Coaxial, like STP, transmits signal through pulses of electricity through a conducting material, in this case copper, which is then insulated by various materials to reduce signal interference and protect it from environmental decay (Figure 2).

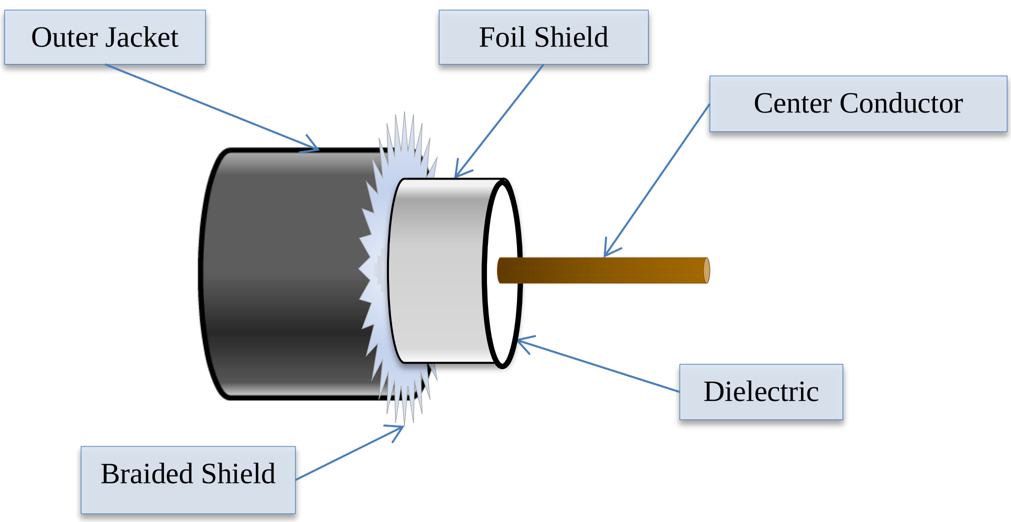


Figure 2: Coaxial cable ("Physical Layer")

Fiber optic cable is unlike any other cable used in the industry. First and foremost, fiber optic cable does not transmit signal through pulses of electricity. Originally developed by Alexander Graham Bell, with the introduction of his Photo phone, optical transmission was thought of as a revolutionary technology. At the time, wire transmission was the established method to transfer information due to its reliability; Bell wished to improve on this by transmitting through air, thus altering his research to focus on light as a means of communication (Hect, 2004). Fiber optic cable transfers information through pulses of light through a translucent yet reflective material such as glass. Today's modern fiber optic cables are comprised of glass fibers bundled together to transmit signal at, or near, the speed of light, faster than any other cable developed today. In just the past 3 years, researchers have been able to obtain speeds of over 100 Terabytes of information per second on the most advanced Fiber Optic Cabling ("Record-Breaking", 2011). Figure 3 below demonstrates in a fairly simple way, how the multiple signals can be passed along one single strand of fiber optic glass, allowing for greater transmission loads.

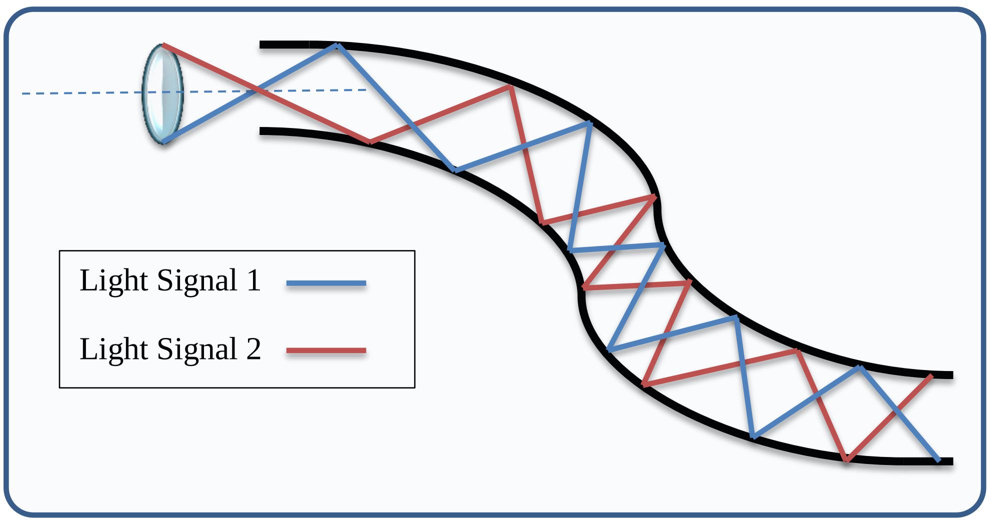


Figure 3: Fiber optic cable signal ("How fast does light", 2013)

Telecommunication companies invest a considerable amount of their budget on continually upgrading their network's footprint, which is the actual interconnected cable infrastructure that allows access to the internet. These companies consume a substantial amount of cabling each day, expanding their grid in order to service more clients. Although, each form of cable offers potential benefits, both economically and through increased reliability, it has become apparent that little research has been conducted on the overall sustainability of network cabling especially with regards to the potential environmental effects of its production, consumption, and disposal. Coaxial cables, for example, are comprised of aluminum, chromium, cadmium, mercury, beryllium, nickel, zinc and copper; some of which are considered quite detrimental to the environment (Andrejiova, 2011). In fact, studies show that these metals make up over 5% of municipal waste (Andrejiova, 2011). Furthermore, taking into account the massive scale of a thriving telecom network, the thermoplastic compound applied to the exterior of the cable places a considerable strain on the environment.

Fiber optic cables utilize a wide array of plastic polymers for protection from not only normal wear and tear, such as tension and bending, but environmental stresses like water permeation and ultra violet radiation. If the fiber optic cable is compromised by any of these forces, the customer and company run the risk of a loss in cable attenuation or signal strength. Whilst reviewing the various types of plastics being utilized in the exterior jacketing of fiber optic cables, this study's goal is to provide an alternative purchasing option that is more environmentally friendly while remaining fiscally sustainable.

Although the production of fiber optic cabling is fairly commoditized, each company holds their plastic mixture as proprietary information. In order to address this, the research detailed in this paper surrounded the most common plastics found in fiber optic cables, substantiated by experts at a large fiber optic manufacturer. The plastics delineated as the most common and making up the bulk of the proprietary mixture are Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC).

The scope of this study centers on the current purchasing model of a large telecommunication company and how those sourcing decisions can be influenced by the introduction and incorporation of a Life Cycle Analysis (LCA) impact assessment. The objective of this research is to shift the purchasing paradigm from merely an economic position, to one that is markedly more sustainable. The source of the information in this study came from a leading telecommunication company, as well as experts in the environmental and fiber optic industries.

CHAPTER 2: LITERATURE REVIEW

In this section a literature review is presented related to sustainability, decision making using Analytic Hierarchic Process (AHP), LCA and the Telecom industry.

- Sustainability

Humphries-Smith (2010) debated the term sustainability with regards to design, stating that Eco-Design, by definition, is the process of designing a product with certain consideration for the environmental impact of the product during its complete life cycle. This however only touches on the Eco-centric, and Techno-centric portions. Sustainable Design delves deeper in to the concept of socio-centric psychology, or the expectations and aspirations of human beings.

Bergmiller and McCright (2009) integrated these two methodologies in order to improve business solutions on an operations level, guiding this research towards a fiber optic cable application. The lean and green methodologies yielded an improved product while also reducing waste and environmental side effects associated with traditional plastics manufacturing.

Xu et al. (2012) applied this methodology in a more ecological area by developing a case study that promoted the “integration of carbon sequestration into sustainable forest management”. Xu et al. (2012) attempted to provide a sustainable framework to evaluate the “Grain for Green” initiative in China which was established to alleviate environmental deterioration and degradation. This study further reinforced the framework for sustainability by including three pillars, Economic, Social and Environmental.

Walker and Brammer (2012) provided an extensive literature review which examines the rise of sustainability framework studies across the globe with regards to the relationship between sustainable procurement and e-procurement in the public sector. Although their review states that there are quite a few studies with regards to sustainability within the supply chain sector, further inspection shows that only eight of the thirty two reviewed incorporate all three pillars suggested earlier.

A second structured literature review of sustainability in purchasing and supply chain management conducted by Miemczyk and Johnson (2011) was directed at the definitions of sustainability at firm, supply chain and network levels. The paper which provided an overview and taxonomy of environmental and social sustainability metrics for sustainable purchasing stated that “relatively few studies have explicitly adopted a social sustainability viewpoint”. This research was directed towards the definition of sustainable purchasing and supply and how these are measured. Seurring and Mueller (2008) concluded that very few studies have successfully addressed sustainability across a whole supply chain.

Other research supported the inclusion of these three categories; Zhang et al. (2011) utilized Economic Development, Environmental Quality as well as Social Harmony among others while attempting to establish a comprehensive evaluation method for the sustainable development of coal cities in China. Concerned with the increasing degradation of Heilongjiang province, Zheng et al. (2011) set out to utilize AHP methodology to compare four major coal mining cities. This same approach can also be seen in the Reza et al. (2010), where the authors attempted to utilize the AHP method to assess the sustainability of flooring systems in the City of Tehran.

❖ Analytical Hierarchic Process (AHP)

In order to conduct complex decision making and prioritization, a great deal of literature research was conducted with regards to the AHP method developed by Thomas Saaty (1994). AHP is a method that has been widely recognized as a useful approach to solving the Multi Criteria Decision Making (MCDM) problem since the 1970's (Zhang (2011), Reza et al. (2010)). This approach allows identifiable objects (criteria and alternatives) to be ranked against each other in a matrix and then totaled providing a score for each object. Al-Azab, (2010) further supports the use of AHP by "providing a convenient, reliable and faster way for the user to make a decision and get the final result of the decision by showing the best alternative based on the most important criteria".

Yupu et al. (2011) evaluated which of the four major coal mining cities of Hegang, Jixi, Shuangyashan and Qitaihe provided the most sustainable development model. Reza et al. (2010), as reviewed earlier when considering the definition and framework of true sustainability, used AHP in conjunction with LCA. Their research attempted to use AHP to investigate sustainable of flooring systems in Tehran.

❖ Life Cycle Analysis

LCA is a process of evaluating a product from a cradle-to-grave perspective. LCA outlines the human and environmental impacts that are a result of a product or process fulfilling its intended function. The phases of an LCA process include Goal and Scope; Inventory Analysis; Impact Assessment and Interpretation (Reza et al., 2010). The United States Environmental Protection Agency (EPA) further substantiates this framework in ISO 14040 (2006). Research conducted by Reza et al. (2010) delves into the definition, scope and use of LCA with regards to an AHP decision.

Gul and Daojin (2007) described Life Cycle Green Cost analysis that evaluates environmental building load and economic performance throughout the life of the building. Gul and Daojin's research takes into consideration the exterior design of a building in China and runs it through a series of environmental modeling trials, comparing the various effects of the exterior design. Gul and Daojin then assessed the cost based on these results.

Birsan, (2010) provided the framework and research on various forms of LCA Software that assisted in delineating SimaPro as the most appropriate modeling software. In this work, Birsan (2010)attempted to use AHP to assist the City of Charlotte's purchasing team by evaluating each software package through a series of pair-wise decision matrixes. Ren and Su (2014) provided further evidence for the benefits of SimaPro when they concluded that due to the extensive databases offered as well as its ease of use, SimaPro was highly recommended. Their work indicated "SimaPro has a comparison function between two products which is very useful for product design optimization and presentation of comparison results'. Based on these studies and resulting recommendations, SimaPro was selected as the LCA modeling software for the study presented here.

Within SimaPro there are a vast number of rating methodologies of which to analyze a certain product. Askham (2012) compared and contrasted the practices and procedures for following LCA methodologies and "REACH" practices. REACH is an acronym for Registration, Evaluation, Authorization and Registration of Chemicals, and is a requirement for the importation or manufacturing of any chemical by a company in the European Union. It's important here to point out that different parts of the world have their own specific metrics for measuring Life Cycle Analysis Impact. In order to be a player in the open market, specific paperwork must be filed identifying the chemical, classification, test results, human and environmental exposure, as well as recommendations for safe use.

Baitz et al. (2005) provided a substantial case towards the use of LCA within the assessment of sustainable procurement. They claimed “Decision-making by life-cycle-approaches is a matter of responsibility and plays a substantial role in corporate identity of innovative companies”. This study specifically covered an example of LCA with regards to PVC cable in the building and constructions sector as well as the electric and electronic equipment sector of which they stated is predominantly cables. Baitz et al. (2005) concluded that “PVC cable does not seem to have significant competitors in many cable applications; therefore few PVC cable LCA studies exist”, which provides an area for this study to explore.

❖ Contribution and Motivation

Although the research posed in this paper relied heavily on well-documented and well-investigated information, it differs substantially from any paper available. There’s not much, if any, substantial research conducted on the long-standing environmental impact of the mass production of plastic materials in fiber optic cabling; let alone the alteration of a purchasing decision based on a well-rounded sustainable model. Although information can be found on the dangers of certain plastics, especially those associated with global waste, there has been little attention drawn to the entire telecommunication industry with its massive network operations.

The intent of this paper is to start asking questions about the type of product telecommunication companies order while examining the potential cost reductions associated with alternative jacketing materials.

CHAPTER 3: SUSTAINABILITY

Prior to the establishment of the EPA, The National Environmental Policy Act of 1969 was drafted and seen as the first substantial acknowledgement of man's effect on the environment (Eason et al., 2011). Eason et al. (2011) stated that it wasn't until 1987 that the World Commission on Environmental and Development formally defined Sustainable Development as an ideal that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Eason et al., 2011). It is clear from this terminology that a sustainable contribution must be viewed in a holistic manner, not merely as a fractional issue. Eason et al. (2011) debated this further by defining the methodology as one of which is "built upon a foundation of economic, social and environmental indicators, sustainable decision making is a highly complex challenge and is predicated on the ability to reconcile both disparate and integrated aspects of the product, process or system under study".

This holistic methodology is more encompassing of the true nature of the world in which we live, one that is reliant on a certain level of balance in order to remain at equilibrium. When changes occur, the entire system can be thrown off balance. This systems view towards the human effect is something that drives the consideration of a three pillar definition of sustainability (Figure 4).

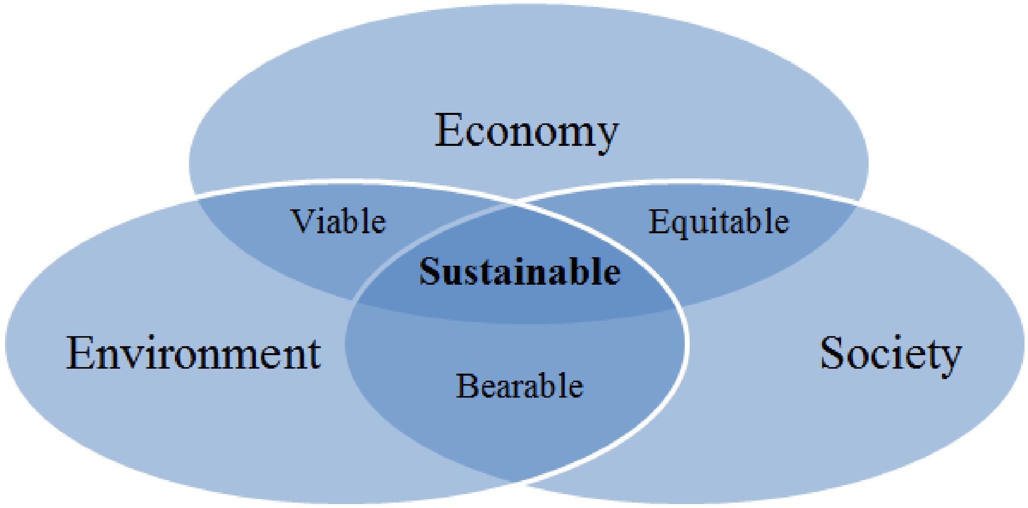


Figure 4: Holistic systems view of the three pillars of sustainability (Eason et al, 2011)

The ideals described by Eason et al (2011) have also appeared in the accounting framework known as Triple Bottom Line (TBL) developed by John Elkington in the mid 1990's, which incorporates three dimensions of performance; Social, Economic and Environmental (Slaper and Hall, 2011). TBL, which Slaper and Hall also referred to as the three P's: People, Planet and Profit, is a methodology and framework that has grown in interest recently in governments, corporations as well as nonprofits in order to account for the entire impact of a business. Comprehension of the scope of these pillars is quintessential to the success of a sustainability study.

- Environmental Sustainability focuses on the direct ecological impact a product or process can have on the Earth. Measurements in the consumption of energy, natural resources, and land, along with the degradation of air and water should always be incorporated. These measurements should not only take into account immediate effects but should value the future impact. This current study utilizes

LCA, in order to produce quantifiable metrics for Environmental Sustainability. The exact metrics of the LCA study that was analyzed in this paper for environmental impact assessment purposes will be covered in detail later in Chapter 6 of this thesis.

- Economical Sustainability touches on the essential monetary aspects of any product or process. Simply put, this should focus on the bottom line or the flow of money (Slaper and Hall, 2011). Purchase, Product, Transport and Disposal costs must all be considered and included in any sort of cost analysis for producing a product. When purchasing a product that is already produced, the financial cost of each product must be weighed, this may uncover an obvious tradeoff between cost, environmental impact and social responsibility. Furthermore, consideration must be given to the overall quality of a product. Due to the fact that this study focuses on the fiber optic cable purchasing habits of a large telecom company, price per foot of fiber optic cable was chosen as the most appropriate metric.
- Social Sustainability is a broad ideology that ranges from health and safety to the balance of social equity. The metrics that can be used for this category depend primarily on the type of business or research being conducted. From unemployment rate, to violent crime rate to the quality of life, Social Sustainability has a broad definition. For the purposes of this thesis, the potential byproducts of cable production which could adversely affect the health and safety of the general population were deemed most appropriate. LCA not only provides quantitative environmental data but also metrics that can be utilized for the Social Sustainability of a product or process. With this in mind, each product was

evaluated equally for its social impact from health and safety perspective. The exact metrics of the LCA study that was analyzed in this paper for health and safety thus for social impact assessment purposes will be covered in detail later in Chapter 6 of this thesis.

Although there has been an agreement over the three pillars of which comprise true sustainability, there has been a constant debate of how to exactly measure sustainability (see e.g. Eason et al. (2011), Reza et al. (2011), Khodaei et al. (2014), Xu et al. (2012), Zhang et al. (2012)). We will elaborate on the discussion on the sustainability metrics next.

3.1: Sustainability Metrics

The quantifiable criteria that define the sustainability metrics, as stated earlier, vary from study to study, however the goal should always remain the same, data with relevance to the stakeholders that would accurately encompass the true definition of sustainability (Eason et al., 2011). Table 1 below, adapted from Eason et al. (2011) provides various metrics for consideration under each sustainability pillar.

Table 1: Examples of sustainability criteria for each pillar (adapted from Eason et al., 2011)

Environmental	Economic	Social
Energy use Resource use (renewable and non-renewable) Emissions (air, water, land) Global warming Ozone Depletion Acidifications Eco-Toxicity impacts Human toxicity impacts Water eutrophication	Macro-economic - Environmental liabilities Micro-economic - Capital costs - Operating costs - Consumer costs - Profitability	Provisions of employment Health and safety of: - Employees - Customers - Public Nuisance - Noise - Odor Public Acceptability

The list is meant to provoke a sense of the thought towards which criteria may lay within each pillar rather than a definitive or authoritative directive. It is up to the stakeholders and those conducting the study to define these categories prior to proceeding with any sort of data collection. Miemczyk et al. (2012) further underline this ideology with their structured literature review of sustainability in purchasing and supply management. Through their systematic analysis of existing literature, another list, similar to that of Eason et al. (2011) was drafted, which also concludes that the definition of criteria is essentially up to the primary stakeholders during the definition of goal and scope prior to any data collection (Table 2).

Table 2: Examples of sustainability criteria for the environmental and social pillars (adapted from Miemczyk et al., 2012)

Environmental	Social
Generic Internal Process material, waste, recycling	Generic internal process
Pollution	Social equity
Cost	Compliance and standards
Compliance and standards	Community
Design	Health & Safety
Energy, CO2, GHG	(Non-) ethical behavior
LCA	Conflict of interest
Strategy	Codes of practice and conduct
Monitoring	
Product	
Risk	

A complete list of criteria of which define sustainability is far numerous to include in such a publication and, if attempted, it would certainly be far too daunting for stakeholders to account for in one individual study (Eason et al., 2011). This suggests that it would behoove stakeholders to limit the study to definitive criteria of which are most relevant and practical to adequately capture sustainability. Again, in this study, it was decided that the focus should be on linear cost of a fiber optic cable to assess economic sustainability; Ozone Depletion, Global Warming, Smog, Acidification, Eutrophication, and Eco-Toxicity to assess environmental sustainability; Carcinogenic, Non-Carcinogenic, Respiratory Effects to assess social sustainability. In addition, product quality and compliance to standards were used as product qualifiers for the analysis, which can be considered as indicators for economic and social sustainability, respectively as well.

It is important to note that each of these criteria will provide its own metric unit for each data point. In order to accurately compare the significance of each of these criteria against one another, normalization must occur through a functional unit. Eason et al. (2011) point out, “the functional unit is also useful for comparing alternate product systems or technologies”. To make this normalization, there was substantial utilization of a multi-criteria decision technique, known as the AHP, which will be further elaborated in Chapter 5.

3.2: Assessing Environmental, Economic and Social Impacts

Once the criteria of each sustainability pillar are defined, the method of data collection and comparison is of most importance. Certainly, consideration was already placed in how this data would be collected during the criteria selection by the stakeholders, but certain criteria provide multiple avenues for compilation. This section presents a brief review over the methods for assessing impacts of fiber optic cabling used in this study.

This thesis chose to perform an LCA due to its proven record for being the most comprehensive method to assess the environmental impacts through the entire life cycle of a product process or system (Eason et al., 2011). The LCA method is exceptional at viewing the study at hand as a holistic system based issue. Any changes in the material or the production method, which could produce an unintended consequence in another area of the lifecycle, can be discovered immediately and reviewed for improvement.

While an LCA is a useful tool in producing meaningful analytical data for environmental issues, the method is only as powerful as its database. Limited lifecycle inventory data is the most critical issue with the analysis of any ethernet cable product

(Eason et al., 2011). Furthermore, as the market and technology advance daily, this data must be continually updated in order to provide relevant and accurate results.

Developments in the sheathing material such as reinforced Kevlar to ensure resistance to accidental tears might be difficult to model in an LCA study without proper data base updates. As found with this thesis, confidential business information can also hinder the true accuracy of research. Certain parts of a product, process or system, may be deemed proprietary and prevent true and accurate data collection.

With regards to the economic assessment methods, cost is at the center but this can be further defined in its location, environmental liabilities, taxes, capital costs, operating costs, consumer costs or profitability. Eason et al. (2011) provided two potential methods for conducting economic assessments; Life Cycle Costing and Eco-Efficiency Analysis. Both of these methods deliver a full LCA of the cost of a product process or system. Due to not only the procurement directive of this thesis but the nature of fiber optic cabling, a simplified purchasing cost analysis was conducted which detailed the price per foot of cable being purchased.

Economic assessment methods are also not immune to their integrity issues; fluctuating manufacturing and capital equipment costs which could alter the price per foot must always be considered. This research was based around the yearly price contract for cable purchased during fiscal 2014, but this price surely fluctuates rapidly between contractual agreements.

Although the methods for assessing the social impacts of a product, process or system are not as developed or definitive as those of the environmental and economic pillars, interest is growing (Eason et al., 2011). In an attempt to reduce the gap, the

United Nations Environmental Program (UNEP) in conjunction with the Society for Environmental Toxicology and Chemistry (SETAC) produced the Guidelines for Social Life Cycle Assessment of Products through the Life Cycle Initiative (UNEP, 2009). This provided a framework for a Social Life Cycle Analysis (SLCA), which follows essentially the same framework of a basic LCA, only differing in the type of data collected (Eason et al., 2011). Due to the close nature of these two frameworks, "some impacts estimated as part of an environmental assessment may also be considered in a social assessment, but case should be taken not to double count impacts" (Eason et al., 2011). This thesis chose to utilize criteria that was provided by the EPA, Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) which provides metrics that include human health impacts which can be considered a social impact (Eason et al., 2011). ISO 14040 (2006) reiterates this by stating that stakeholders must "seek to minimize or eliminate the negative health impacts of any product or service provided by your business". Issues related to the social assessment methods revolve around the inadequate methods for addressing the criteria delineated in such a new area of research.

3.3: Making Sustainable Decisions

When the analysis has concluded and the data is presented, decisions must be made with regards to the sustainability of the product, process or system. Figure 5 provides a high level view of a sustainability decision analysis framework.

In order to execute the decision analysis framework described in Figure 5, a decision making method is needed that most appropriately acknowledges the views and goals of the stakeholders. In this study, AHP was selected due to its well-established technique that helps assessing decision makers' preferences on each decision criteria (both qualitative and quantitative) and alternatives both in single decision maker and group decision settings (Saaty, 1980). The AHP technique and the decision making process will be discussed in detail later in Chapter 5. Once the best alternative is selected sensitivity analysis must be completed in order to verify the consistency and validity of the results, and if amendments are required, the process will repeat in order to more properly target the sustainability criteria further.

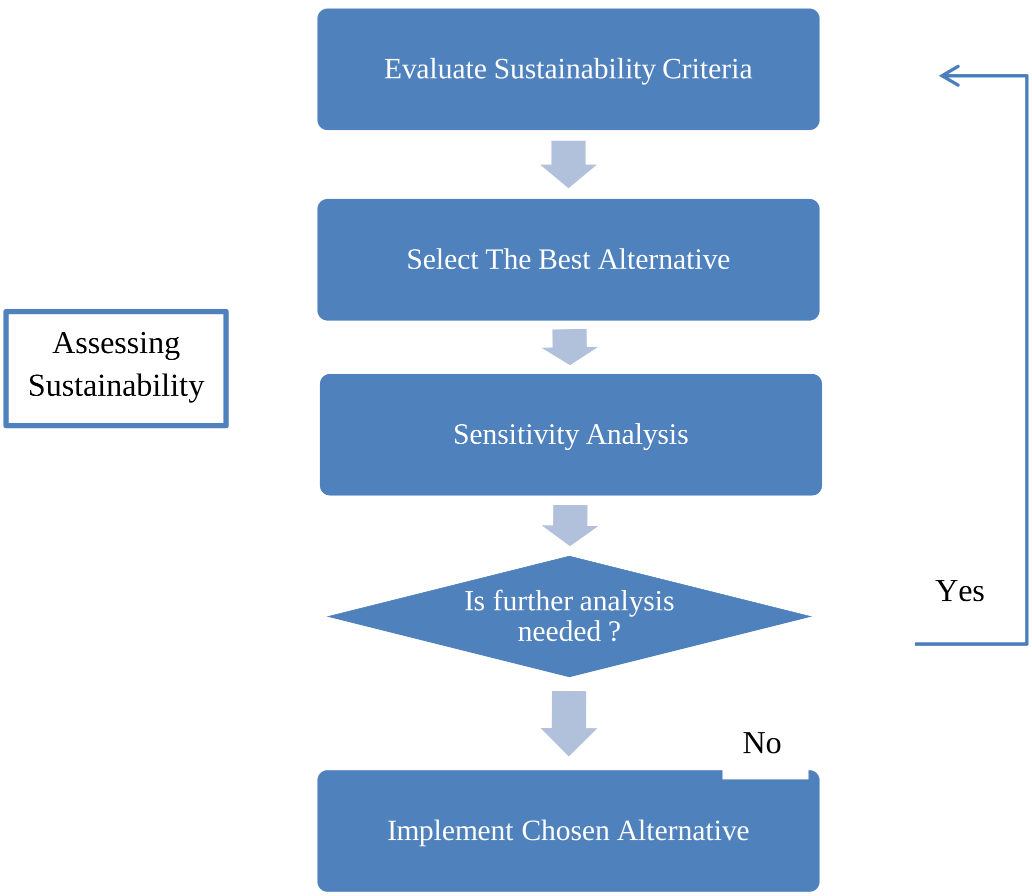


Figure 5: Decision analysis approach (adapted from Eason et al., 2011)

CHAPTER 4: TELECOMMUNICATIONS INDUSTRY

Spurned by the explosion of the internet, the ever-increasing need for faster multimedia information transmission has created a large demand for expansive cable networks. The telecom industry, as stated before, is built upon a range of cable technologies, but due to the increasing size and speed requirements, local telecom networks are being forced to upgrade in order to support advanced signal processes. Using the 5P Framework for Teaching and Characterizing Supply Chain Effectively shown in Figure 6 below we are able to see a clearer picture of what takes place within this industry

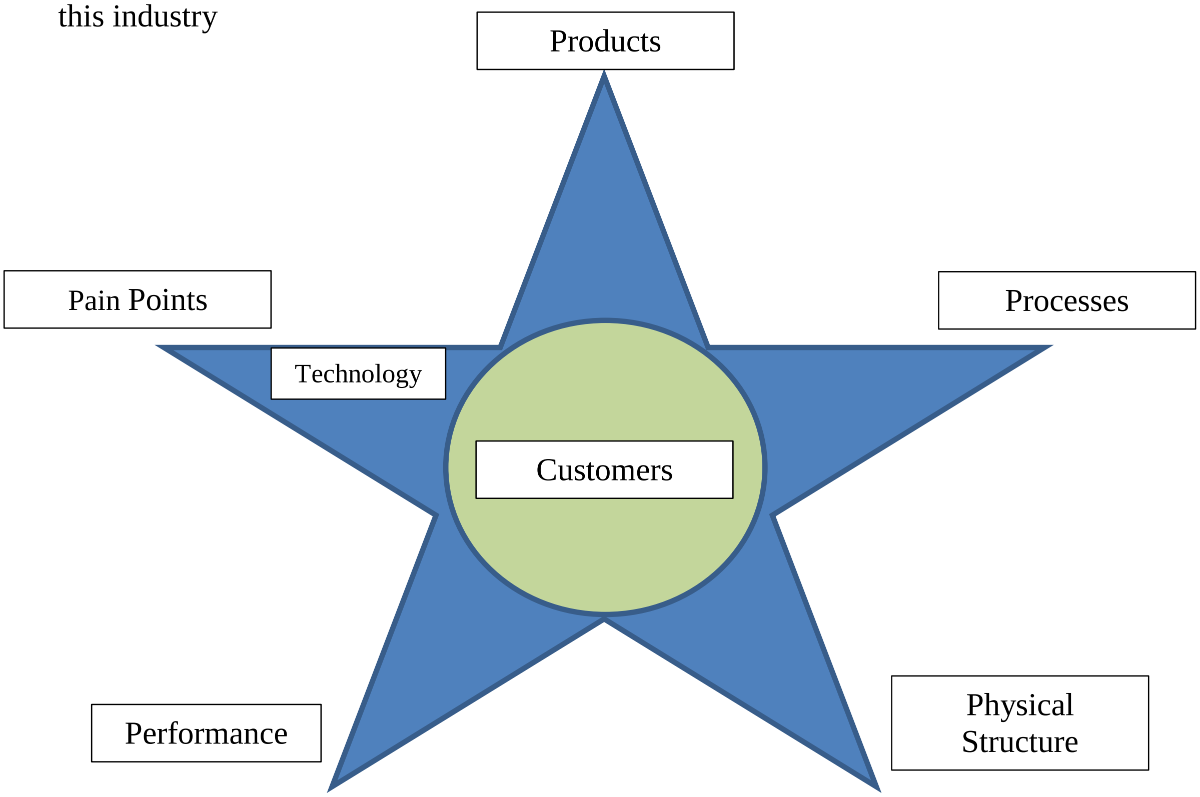


Figure 6: 5P Framework for teaching and characterizing supply chains effectively (Ozelkan, 2006)

4.1: Customers

With each passing month the dependence on internet access with regards to business transactions is becoming more evident. The major volume of the customers in this industry are from residential users. However the focus of major Internet Service Providers (ISP) over the past decade has been to expand their business to business enterprises ("Improving Efficiency", 2014). Due to the saturation of the basic consumer market, growth in this industry is extremely reliant on business to business customers. When basic consumers require internet service, it can be installed typically within a week's timeframe due to the expansive hub network already established in their neighborhood or housing development. This is not necessarily the case for most businesses, which now essentially require internet products for business transactions. This new business model requires extensive construction to place new fiber network cabling to previously unserviceable buildings. Furthermore, businesses often require much higher levels of bandwidth in order to keep their businesses running. Hospitals, law firms, corporate buildings, colleges and call centers require incredibly large fiber optic networks in order to grow their business.

4.2: Products

Although these internet providers develop a networking solution product, they should be actually viewed as a service company. With this in mind as well as the rapid expansion in technology, these product solutions have an incredibly short life cycle if they are not designed appropriately enough. The physical product must be developed to withstand multiple soft upgrades while maintaining the same technology.

The lead times to bring these products can vary depending on what the customer has asked for and the amount of construction necessary to provide service. Once a customer has the necessary components and equipment installed for service these highly innovative products can produce an incredible margin as the sunk cost in the service occurs upfront.

Not only are these businesses reliant on secure dedicated internet access, but often require secure Ethernet Private Lines (EPL) which tie each of their corporate locations together, creating a network for their business. This creates an incredible demand for millions of feet of cable to complete. The construction necessary for such solutions can run in to the tens of thousands of dollars for each customer, all of which is typically covered by the ISP due to the eventual return on investment over the term of the contract.

Dedicated Internet Access (DIA) is one of the best-selling products of most ISPs due to the security and large guaranteed bandwidth available. Customers can utilize this product as well as the rigorous network back bone to establish a reliable telecommunications network between multiple business locations simultaneously. Other products requiring fiber optic cabling range from standard trunk telephone lines to fiber optic hospitality service.

4.3: Pain Points

Although the fiber optic network is extremely adaptable to many product suites, the continual advancement of technology in the telecommunications industry provide potential pain points with regards to product lifecycle. Each year this technology is being pushed further for efficiency and speed over a physical network that was installed in previous years at a premium cost. The product lifecycle solution is often very short, requiring upgrades. In order to reduce the issue of replacing the physical network each year, companies must invest and construct a network in which they are confident can handle traffic well beyond the current demands. This incredibly large initial capital investment provides a large barrier of entry to the industry.

Other issues that ISPs encounter run in parallel with standard utility companies when it comes to major weather patterns. Due to the part of the physical layer of the fiber network being strung along power poles, devastating storms may carry the potential to bring down power lines, often damaging localized fiber optic lines; analyzing and predicting weather patterns in order to restore fiber optic service is of great concern to ISPs.

Lastly, as with any sort of service provider boarding on utility in its function, the customer has an incredibly high expectation due to reliance for survival. The service level agreement delivered to customers who sign with the service provider studied in this thesis, guarantees their network will be up and running 99.99% of its life time.

4.4: Performance Measures

In order for these connections to occur, however, an extensive network of fiber optic cable needs to be laid in a timely manner. The ISP in this study maintains internal due date metrics which are used to track the efficiency of bringing an order to service. The goal of these due dates is to reduce the interval between contracts being signed with a customer to the date service is delivered. The due date intervals vary between 30 to 90 days depending on the geographical location of the order and the amount of construction, or kilometer of fiber required to bring service to that customer. As the business ramps up to keep the actual time table below these due date intervals, each part of the business must be running as efficiently as possible. Fiber procurement is a major factor in completing the work necessary in a timely manner. If the proper cable is not on hand for construction, splicing or installation, major operational delays will occur.

4.5: Physical Structure

The physical structure in this industry includes not only the network footprint of each ISP but also the warehouses, distribution network and multiple players that ensure a speedy and reliable product. All internetproviders must maintain warehouses which house not only modems and switch equipment but also the physical network cabling that is required for construction to bring service to their customers. These warehouses are typically established in cities, allowing a central location point for technicians and construction workers to pick up necessary materials daily.

It is worth noting that that since their inception in the late 1970’s, transmission line speeds have increased on an order of magnitude, today these transmission lines can handle hundreds of terabytes of data per second (Dillow, 2011). It is with this reasoning that there is a monumental paradigm shift in global communication towards the use of fiber optic cabling, creating a larger demand for an upgraded physical layer of the network. ISP customers are demanding lighting fast speeds and companies are responding. Verizon is now offering its 500Mbps download speeds for their FiOS product subscribers, while Time Warner Cable Business Class can provide DIA lines ranging from 3 to 10Gbps (Tech Specs, 2014).

According to Google, there exists a plan to expand their Fiber network to 34 cities and 9 metro areas within the coming decade (“Expansion Plans – Google Fiber”, 2014).

Companies are pushing their chips all-in to cash-in on this seemingly uncapped demand for incredible data speed, in doing so creating an even larger worldwide demand for fiber optic cable production. In fact, according to a 2014 press release, Verizon Wireless (2014) had laid its 89 millionth foot of fiber optic cable in just its New York City network alone. Impressive numbers like these only reflect the investment of one ISP in geographic region; surely the major manufacturers of fiber optic cable have their hands full, filling orders with no end in sight.

Figure 7 below provides a basic representation of a Hub and Spoke Fiber Network. This network is connected through an array of physical hubs and switches which all must be connected through the physical layer of fiber optic cabling. This figure demonstrates how a central campus site can be networked with private ethernet lines to subsidiary branches. These branches will be spliced with local hubs in the neighborhood with fiber optic cabling. From there these hubs will connect to a central node of which can be accessed through a private IP address for that company.

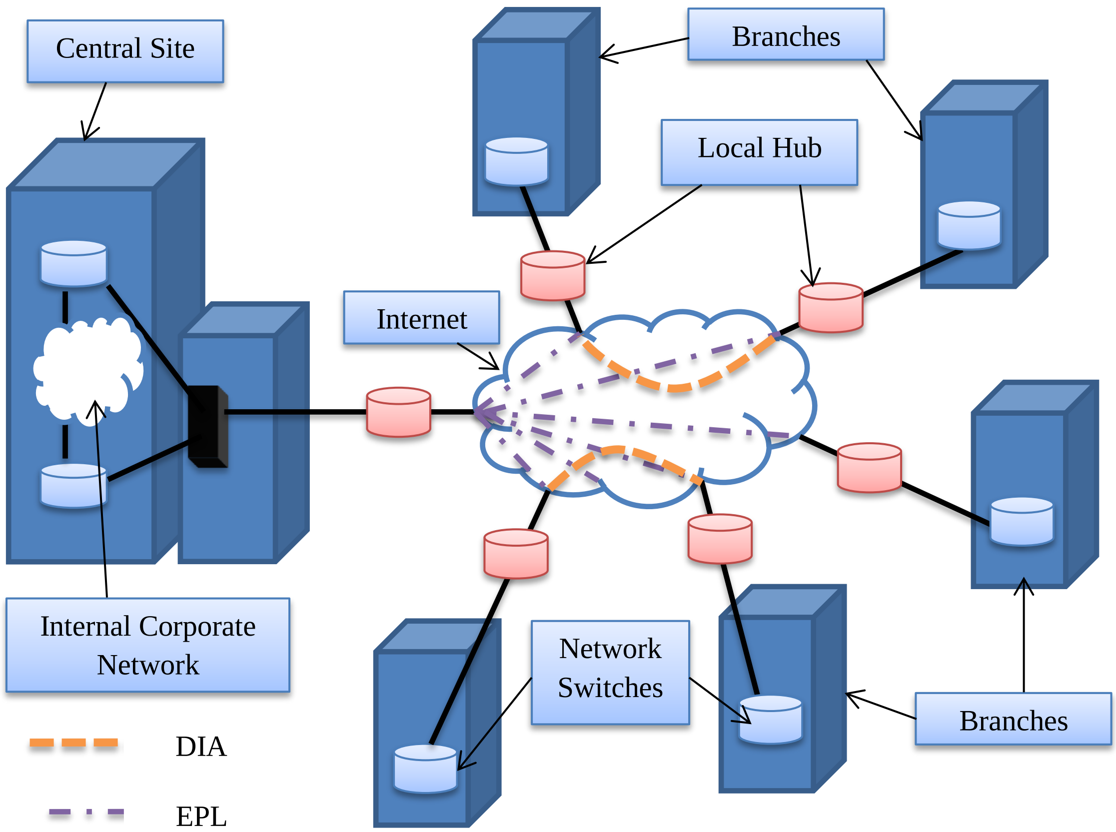


Figure 7: Ethernet hub and spoke network with DIA and VPN ("Dynamic Multipoint VPN", 2013)

4.6: Processes

As shown in Figure 8 below, there are many players in the Telecom industry. The industry process map provided in Figure 8 shows which players are involved in which stage of the industry process.

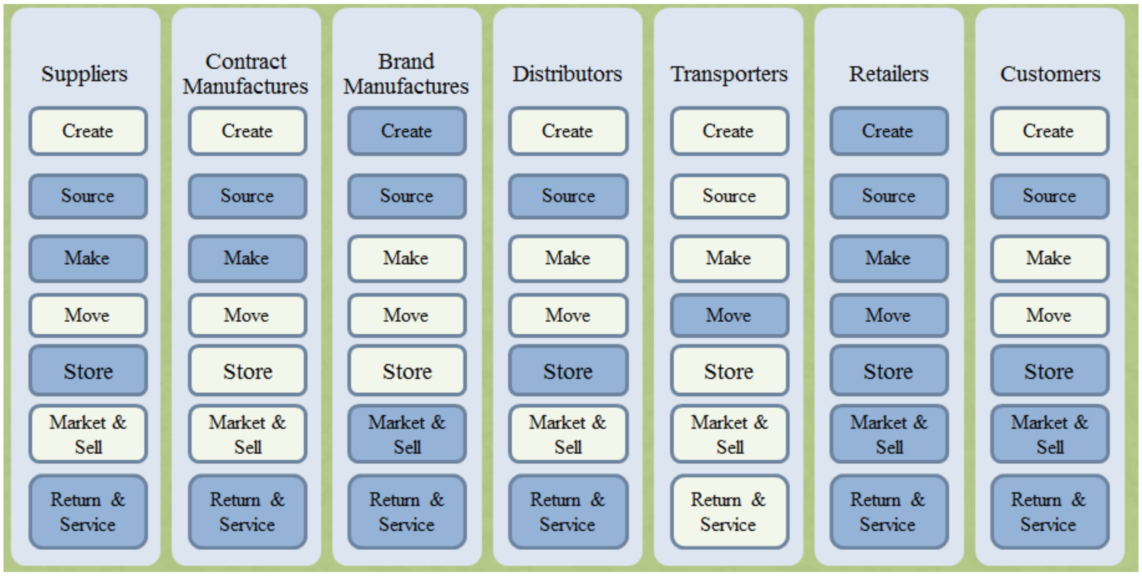


Figure 8: High level supply chain model of processes telecommunications Industry (based on Ozelkan, 2006)

As shown by Figure 9 below, the supply chain in the telecom industry involved with developing, selling and implementing new products as well as developing the network backbones is extensive. The process of bringing a reliable product to market takes extreme cooperation and communication, especially when lead times between development and launch are being shrunk due to market and technology forces (Reyes et al., 2002). This is a struggle that most businesses deal with on each and every sale. The focus of this study was an ISP and a contract manufacturer of fiber optic cables. The long standing relationship between these two businesses allowed for favorable contract negotiations due to the guaranteed demand by the ISP. Once the contract negotiations have completed, the cable is purchased with a projected monthly demand quota with additional orders placed during times of peak demand.

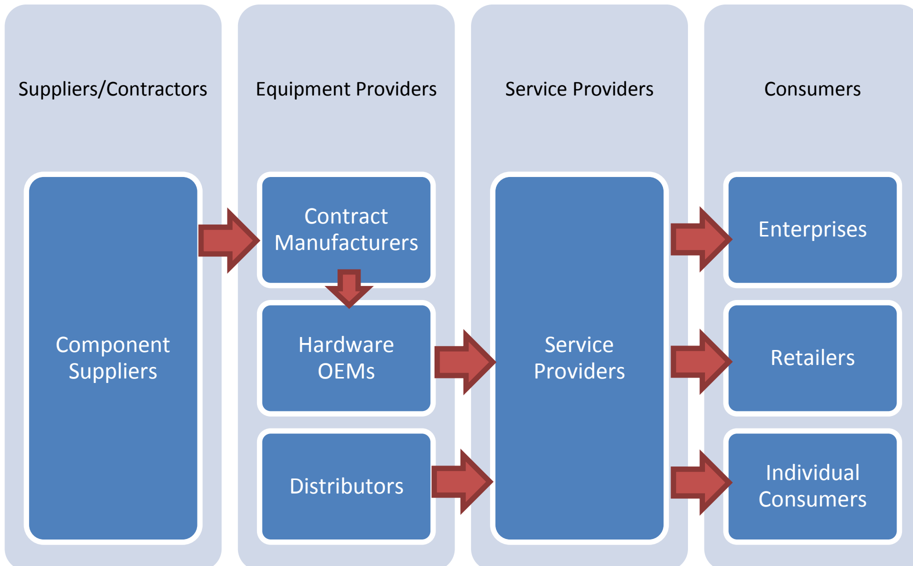


Figure 9: High level supply chain model of telecommunications industry (based on Reyes et al., (2002) and Ahmad & Saifudin, (2014))

4.7: Technology

"The distinctions between telephony, data and cable networks are becoming blurred; nowadays success of an increasing number of companies depends on the access and transmission of data on the internet" (Jain, 2001). In recent years fiber optic cables have demonstrated a huge increase in transmission capacity, all while achieving an incredibly low bit error rates compared to traditional copper wire systems (Jain, 2001). Not only are these newer networks faster, but are also increasingly more reliable when considering data integrity.

In order to meet the demand of these construction jobs for network expansion, large ISPs maintain their own contracts with fiber optic cabling manufactures to ensure that they have enough cable for each project they secure. These contracts can run month-to-month for emergency surplus or span years in order to cover basic fiber requirements. This study was able to secure contract information between a large telecom company and their most trusted fiber manufacturer.

CHAPTER 5: METHODOLOGY

In this section, we will describe the decision framework and methodology for making sustainable purchasing decisions for fiber optic cabling. As discussed earlier, in order for any product or process to be deemed sustainable, its design and production must acknowledge and embrace efficiencies economically, environmentally and socially (Humphries-Smith, 2010). This paper addresses all three through the green purchasing decision framework, which is shown in Figure 10. This study conducted several forms of analysis to quantify the economic, environmental and social pillars of the green purchasing decision. More specifically, cost and quality analysis will be performed for assessing the economic pillar, while environmental and social analysis will be measured using LCA. All these analyses will be combined into a green purchasing decision using the AHP technique. In the next sections, we will provide a more detailed overview of the methodologies followed

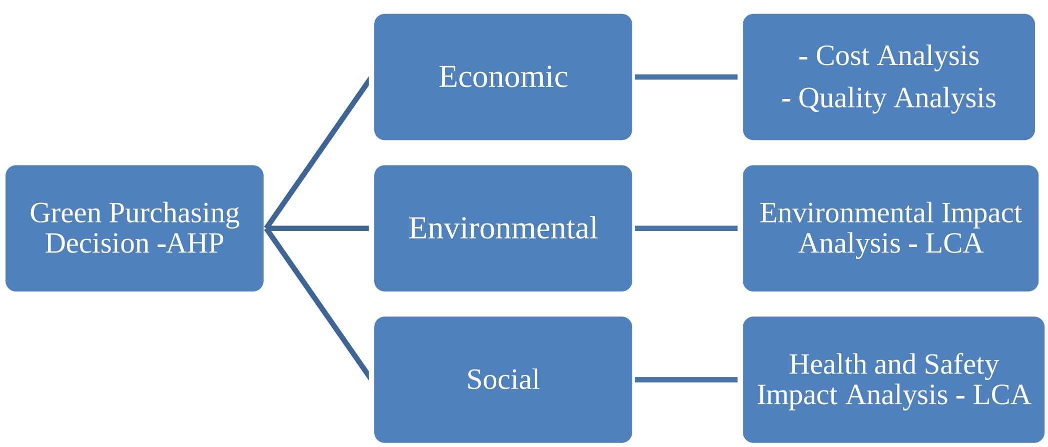


Figure 10: Green purchasing decision methodology

5.1: Analytical Hierarchy Process

Developed by Thomas Saaty in the 1970's (1980) AHP is a structured procedure for making concise decisions based on mathematical and psychological attributes. Not only can AHP assist in individual decisions, it can also be used as a tool to direct groups of decision makers to a common goal. AHP uses a multi-level hierarchical structure of objectives, criteria, and alternatives to produce mathematical comparisons of each outcome or decision (Figure 11).

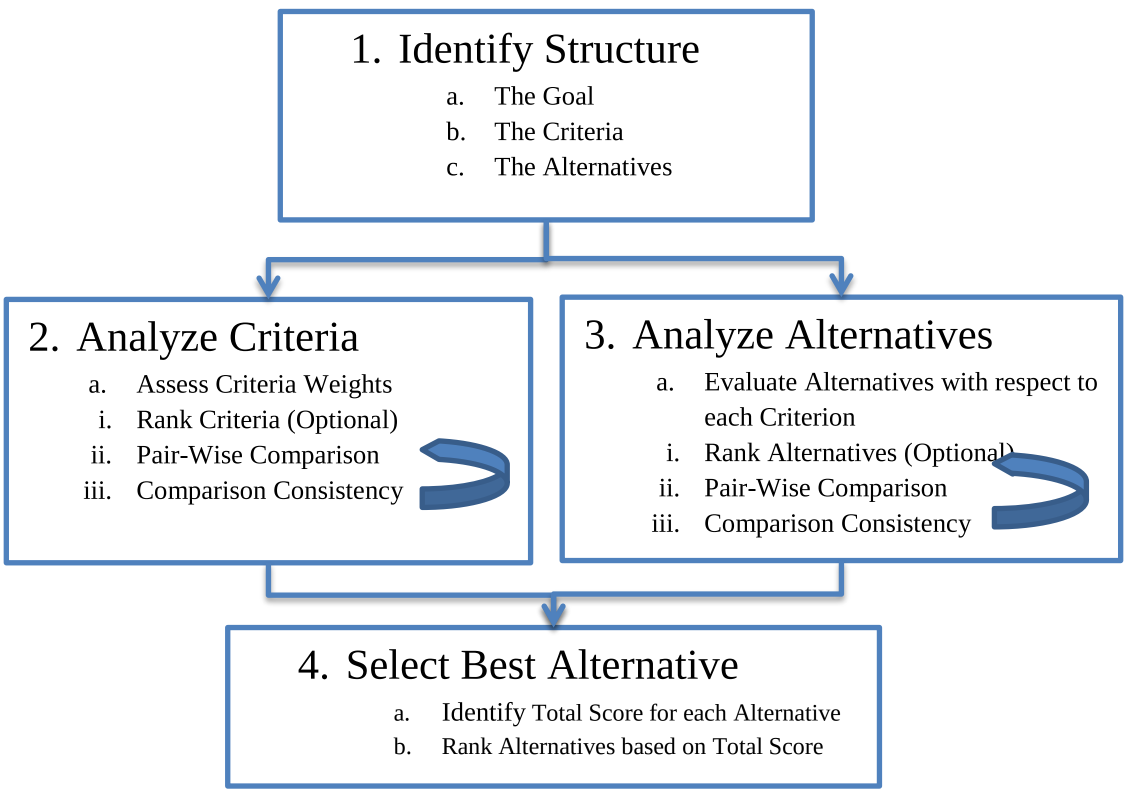


Figure 11: AHP methodology (Source: Lecture notes of Dr. Ertunga C. Ozelkan)

The procedure to conduct AHP with regards to a certain situation begins at the decomposition or structural identification of the problem at hand. Once the Goal, Criteria, and Alternatives are defined the Criteria can be analyzed. When assessing the Criteria, they first must be ranked in order of importance which serves a consistency check after the Pair-Wise Comparisons (PWC) are completed.

The PWC method allows the study to rate each criterion against one another, in a head-to-head evaluation. Once this was accomplished, the Geometric Mean of these PWCs were tabulated. Their Normalized Weights were calculated next by dividing this mean by the sum of the Geometric Means. Table 3 below provided by Saaty and presented by Reza (2010) provides the fundamental scale for developing a PWC matrix.

Table 3: AHP scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over the other
5	Strong importance	Experience and judgment strongly favor one activity over the other
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of highest possible order of affirmation
1,2,4,6,8	Intermediate values	

Table 4: Criteria weight calculation | AHP

		Criteria			Geometric Mean	Criteria Weights
		A	B	C	$\left(\prod_{i=1}^{n} k_i\right)^{\frac{1}{n}}$	
Criteria	A	1	*a/b*	*a/c*	$A = \sqrt[3]{(1)\left(\frac{a}{b}\right)\left(\frac{a}{c}\right)}$	$W_A = (A \div T_w)$
	B	*b/a*	1	*b/c*	$B = \sqrt[3]{\left(\frac{b}{a}\right)(1)\left(\frac{b}{c}\right)}$	$W_B = (B \div T_w)$
	C	*c/a*	*c/b*	1	$C = \sqrt[3]{\left(\frac{c}{a}\right)\left(\frac{c}{b}\right)(1)}$	$W_C = (C \div T_w)$
					$T_w = \sum_{i=A,B,C} i$	

Table 4 above provides the method for conducting a PWC. Using the definitions provided in Table 3, each Criteria is given a score based on its performance against each other as shown in the matrix in Table 4. The Criteria Weights are tabulated by dividing each of the Geometric Means by the sum of the Geometric Means for each Criterion.

The same PWC method is also used for the evaluation of each Alternative with respect to each criterion, as shown in Table 5 below. For example, Alternatives X, Y and Z, are rated head-to-head, with respect to Criteria A, this is repeated for Criteria B and C.

Table 5: Alternative score calculation | AHP

		Alternatives			Geometric Mean	Alternative Score
Criteria A		X	Y	Z	$\left(\prod_{i=1}^{n} k_i\right)^{\frac{1}{n}}$	
Alternatives	X	1	*x/y*	*x/z*	$X = \sqrt[3]{(1)\left(\frac{x}{y}\right)\left(\frac{x}{z}\right)}$	$S_X^A = (X \div T_s)$
	Y	*y/x*	1	*y/z*	$Y = \sqrt[3]{\left(\frac{y}{x}\right)(1)\left(\frac{y}{z}\right)}$	$S_Y^A = (Y \div T_s)$
	Z	*z/x*	*z/y*	1	$Z = \sqrt[3]{\left(\frac{z}{x}\right)\left(\frac{z}{y}\right)(1)}$	$S_Z^A = (Z \div T_s)$
					$T_s = \sum_{i=X,Y,Z} i$	

The Alternative Scores (S) are then multiplied by each of their respective Criteria Weights (W), shown in Table 6 below. The sums of these comprise the total Alternative Score (WS) which will provide a quantitative conclusion for the study being performed.

Table 6: Calculation the of best alternative | AHP

	Criteria A	Criteria B	Criteria C	TOTAL
Alternative X	$WS_X^A = (W_A \times S_X^A)$	$WS_X^B = (W_A \times S_X^B)$	$WS_X^C = (W_A \times S_X^C)$	$\sum_{i=A,B,C} WS_X^i$
Alternative Y	$WS_Y^A = (W_A \times S_Y^A)$	$WS_Y^B = (W_A \times S_Y^B)$	$WS_Y^C = (W_A \times S_Y^C)$	$\sum_{i=A,B,C} WS_Y^i$
Alternative Z	$WS_Z^A = (W_A \times S_Z^A)$	$WS_Z^B = (W_A \times S_Z^B)$	$WS_Z^C = (W_A \times S_Z^C)$	$\sum_{i=A,B,C} WS_Z^i$

In order to establish a basis for how fiber optic cable is currently being purchased, surveys were administered to purchasing leaders within a large telecom provider. Once the criteria were established, these volunteers were then asked to systematically compare the elements against one another as shown earlier.

The last step of this process is to check the Logical Consistency of the PWCs using the equations below. λ_{max} was calculated by taking the average of the total criteria rankings. Next the Random Index (RI) was identified using the average value of Consistency Index (CI) for randomly chosen entries. This RI table can be found in the appendix. Lastly, the Consistency Ratio (CR) is calculated by dividing the CI by the RI as seen by Eq. 3 below (Xu et al., 2012; Saaty, 1980).

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{g_i}{w_i} \qquad [Eq. 1]$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad [Eq. 2]$$

$$CR = \frac{CI}{RI_n} \qquad [Eq. 3]$$

AHP has the ability to solve complex decision making problems involving multiple alternatives and criteria. The benefit of this type of analysis with regards to decision-making is that certain unquantifiable elements can be given a mathematical weighting through proper expert evaluation.

5.2: Life Cycle Analysis

LCA is a modeling technique used to assess all possible environmental impacts of a certain product or process by which accounts for a cradle-to-grave scope. For the purposes of this report, SimaPro 8 Software was utilized for its modeling ability and extensive database inventory. Figure 12 below provides a Life Cycle Model which takes into account all parts of the product or process. Beginning with the extraction of raw materials, through manufacturing, distribution, reuse, recycling and eventually waste, a system will incorporate multiple inputs of energy, natural resources and raw materials. Each of these steps in the process must be accounted for, as well as the outputs along this life cycle.

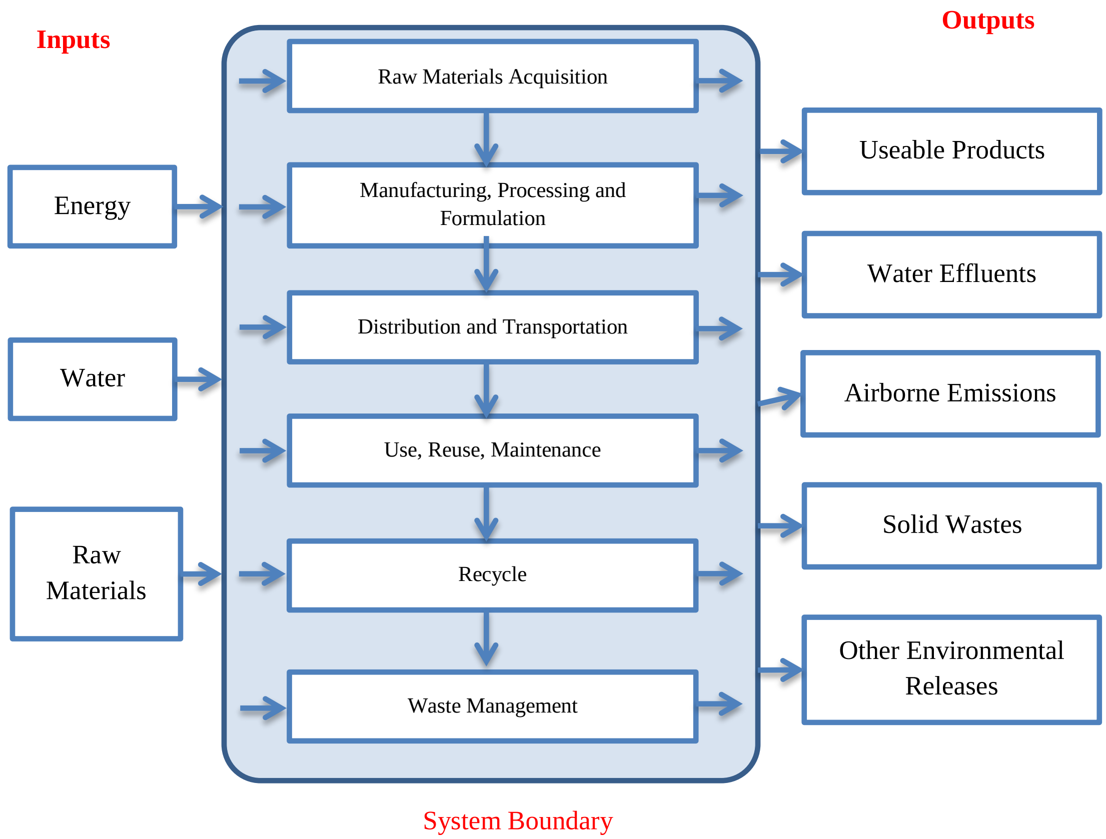


Figure 12: Life cycle analysis model (Chen, 2008)

Along with various life cycle impact assessment methods, SimaPro 8 software pools together large life cycle inventory databases with a broad international scope. LCA provides a view of nearly any environmental effect a product, process or procedure would incorporate, from the extraction of raw materials through its end-of-use. SimaPro 8 software has the ability to model and compare multiple products side by side. This is a beneficial tool when attempting to pinpoint which part of a product or process is the most impactful on the environment. With this information in hand, businesses and governments alike can make sound changes to their product choices. This database is so detailed that one could even model the transportation costs of a product or process; from what size truck was used to half-mile transit increments.

SimaPro 8 allows user to select a series existing products, materials or processes to incorporate in their analysis. For this research, one foot of fiber optic cable was modeled by building each component of the cable from the material list. The benefit of SimaPro 8 was its vast database of verified materials. Products are built in SimaPro 8 in the series of which they are created. Users have the ability to use processes that include the extraction of rock or minerals from the earth to smelting ore or even plastic extrusion. Due to the fact that the production of these cables are virtually identical, the focus of this thesis was with the material used in exterior jacketing. The same basic fiber optic cable model was built for each fiber cord, with the only difference being in the exterior material selected. Once the product was built, it was analyzed by various standard forms of assessment. Figure 13 below depicts the standard process by which products and processes are modeled in SimaPro8.

Figure 13: SimaPro 8 process

By using the TRACI method included in the SimaPro 8 software, nine impact categories were established for further review. TRACI was developed by the United States EPA in order to better understand, analyze, and correct chemical pollution in the United States and abroad. The categories associated with a TRACI study include Ozone Depletion, Global Warming, Smog, Acidification, Eutrophication, Carcinogenic, Non Carcinogenic, Respiratory Effects and Eco-toxicity. These criteria were used to assist in decision-making frameworks for social and environmental categories that will be discussed later in this paper.

Dr. Dongwook Kim, Dr. Helen Hilger, Dr. David Kinnear, and Dr. Shubhashini Oza, cross examined these impact categories using the AHP methodology, thus providing proper weighting and ranking for the environmental and social criteria. By taking the data from these criteria in the LCA software and multiplying it by the weighting provided by the environmental and sustainability industry experts a final score was tabulated, defining the most environmentally and socially responsible plastic.

5.3: Cost Analysis

Contract data between a large telecommunications provider and a large fiber optic supplier contributed to the financial information used in this paper. This financial information included the current market price for various forms of fiber optic cables based on the exterior jacking material used. The purchasing price was scaled down to USD per foot of fiber cable. As with any company, especially one dealing with such large quantity of cabling, even the smallest cent or fraction of a cent can mean millions of dollars annually. Due to this, these prices, although appearing to be of little consequence, mean a great deal to the manufacturer and the consumer.

Although these documents detailed every cable that was purchased over a period of a month by the telecommunications provider, the data was mined in order to delineate the specific cables of which were bought not only in large quantities but whose chemical structure was primarily of the plastics in question, Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC). Each cable was rated against each other based on its cost through the AHP methodology by a purchasing expert. By using AHP methodology this study was able to tabulate a raw score for the most cost effective plastic offering.

Unfortunately, due to corporate policy and ongoing contract negotiations, both the supporting financial documents and the exact mixture of each plastic were deemed proprietary information and have been redacted from this report.

5.4: Quality Analysis

In order to fulfill the economic responsibility, fiber optic cables must meet certain metrics which verify their ability to perform effectively when placed under certain levels of stress. This is considered quality control of the product delivery; if these cables are not deemed to be of a certain quality, an entire shipment can be rejected by the purchasing company. These metrics delve in to aspects of the cable including its attenuation, diameter, strength, durability, length, color coding, and permeability and Restriction of Hazardous Substances Directive (RoHS) certification. Large ISPs, which consume hundreds of miles of cable annually, typically will provide their own spec sheet to fiber optic cable manufactures, which detail the exact product they are willing to accept. The manufacturer must fulfill all of the requests of this document in order for the product to be deemed of a certain quality and thus acceptable for purchase. These specifications are researched and thoroughly vetted by experienced material engineers at each company. Therefore, this study viewed all cables as equal in quality, as long as they satisfy the performance specifications.

Due to the fact that all cables used in this study needed to satisfy the required specifications, quality becomes a product qualifier; therefore, for further analysis, this study focused on cost analysis.

CHAPTER 6: ANALYSIS

In this section, we will describe the AHP analysis following the steps as described earlier in Figure 11.

6.1: Step 1 | Identify Structure

The overall purchasing structure was formed around the three pillars of sustainability mentioned earlier, involving Economic, Environmental and Social criteria, with the goal defined as selecting the best jacketing for fiber optic cabling. Cost was selected as the Economic Criteria, TRACI environmental impact factors were selected for Environmental Criteria and Social Criteria. Based on the TRACI outputs, the Environmental Criteria were selected as Ozone Depletion, Global Warming, Smog, Acidification, Eutrophication, and Eco-toxicity and the Social Criteria were selected as Carcinogenic, Non Carcinogenic, and Respiratory Effects.

The Alternatives, which are three forms of plastic regularly used in the jacketing of fiber optic cabling, were identified as, High-Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), and Polyvinyl Chloride (PVC).

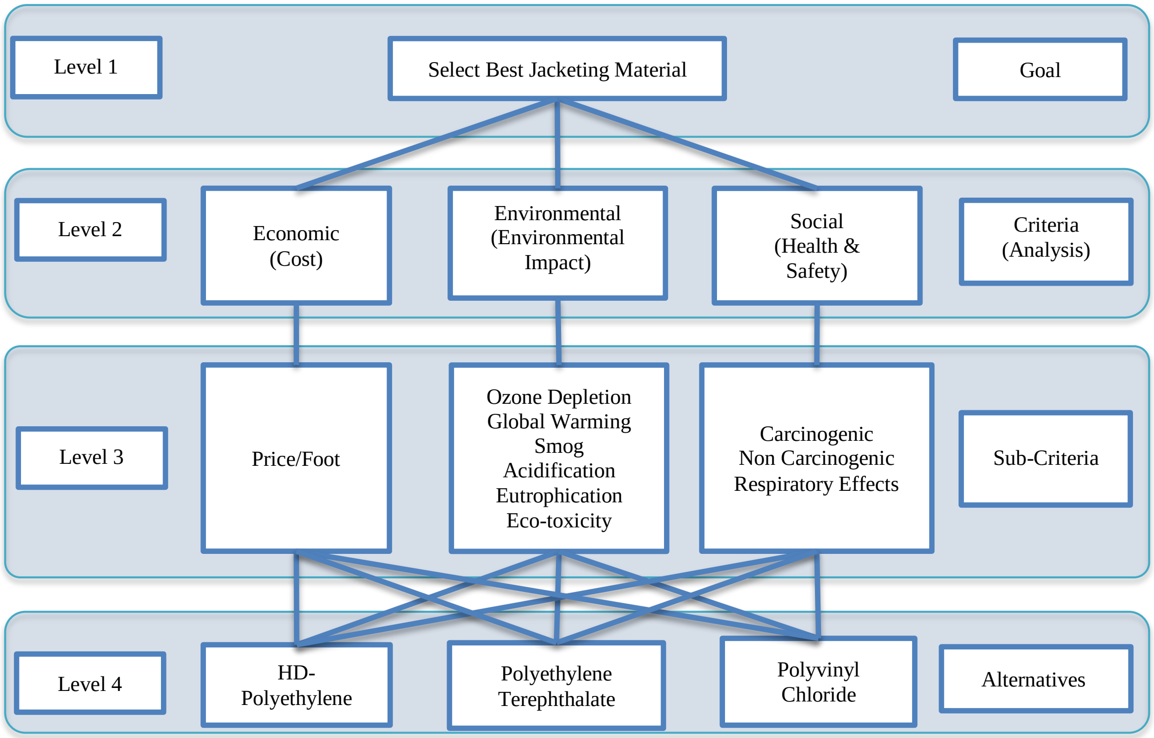


Figure 14: AHP structure

6.2: Step 2 | Analyze Criteria

In order to establish a basis for how fiber optic cable orders are currently being placed, surveys were administered to procurement experts in a large telecom company. Once the Economic, Environmental and Social Criteria were rated against each other through the AHP process listed above, a normalized weight was established. Table 7 below shows the geometric mean of the AHP tables filled out by the purchasing experts. As you shown in Table 7, the Economic Criteria was defined as the most important criteria when procurement experts were considering which type of cable to acquire. From this data, interest grew with how the cable purchasing decision would change if more emphasis were placed on the Environmental Criteria, which was given little to no initial attention. The PWC shown in Table 7 was confirmed to be consistent, registering a CI of 0.008 a Consistency Ratio of 0.014, well below the CI threshold of 0.10.

Table 7: Geometric mean of fiber optic purchasing decision model

		1	2	3	**Geometric Mean**	**Criteria Weights**
		Economic (Cost)	Environmental (Environmental Impact)	Social (Health& Safety)		
1	Economic (Cost)	1.000	4.440	3.557	2.51	65.90%
2	Environmental (Environmental Impact)	0.225	1.000	0.550	0.50	13.10%
3	Social (Health& Safety)	0.281	1.817	1.000	0.80	21.00%
	Consistency Index	0.008	0.069	**Total**	**3.81**	**100.00%**
	Random Index	0.580	0.580			
	Consistency Ratio	0.014	0.119			

For most businesses of which are never posed with such a question, it should come as no surprise that the procurement expert should place such an overwhelming emphasis on cost. Prior to this evaluation, the ISP presented extensive evidence that they purchase cables nearly exclusively comprised of Polyvinyl Chloride. The paper strove to confirm that given the weighting above, the ISP was already purchasing the correct type of fiber optic cabling.

❖ Economic Criteria Analysis

Within the framework of this paper, cost was broken down in to USD per foot of cable purchased. The quality of each cable was used as a product qualifier in our analysis, and was assumed equal, as long as they satisfy the required specifications.

❖ Environmental and Social Criteria Analysis

A number of sustainability industry experts were asked to evaluate the Environmental and Social Criteria through PWC decision matrixes. Among these experts were Dr. Kim, a recent graduate of the Infrastructure and Environmental Systems PhD program at UNC Charlotte (who has completed his dissertation on Model Development and System Optimization to Minimize Greenhouse Gas Emissions from Wastewater Treatment Plants); Shubhashini Oza, a Research Associate at the University of North Carolina at Charlotte; Dr. Helen Hilger, who holds a Ph.D in Civil Engineering from North Carolina State University and is published in sustainable engineering planning, design and management; Dr. David Kinnear, who is a vice president of HDR engineering and an expert in the environmental industry. These professionals were asked to rank the environmental criteria against each other based on the definitions listed in Table 8.

Tables 9 and 10 below show the relative importance weighting assigned to the Environmental and Social Criteria used in this research. As you can see by Table 9, there was a greater Environmental concern placed on Global Warming and Acidification; while Table 10 clearly shows an utmost concern with products or processes that produce Carcinogenic byproducts.

Table 8: TRACI impact categories

Environmental	Ozone Depletion	The ozone layer can be depleted by free radical catalysts, including nitric oxide (NO), nitrous oxide (N2O), hydroxyl (OH), atomic chlorine (Cl), and atomic bromine (Br). While there are natural sources for all of these species, the concentrations of chlorine and bromine have increased markedly in recent years due to the release of large quantities of man-made organ halogen compounds, especially chlorofluorocarbons (CFCs) and bromo-fluorocarbons
	Global Warming	A gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide and chlorofluorocarbons
	Smog	Fog or haze combined with smoke and other atmospheric pollutants.
	Acidification	Ongoing decrease in the pH of the Earth's oceans, caused by the uptake of carbon dioxide (CO2) from the atmosphere. An estimated 30–40% of the carbon dioxide released by humans into the atmosphere dissolves into oceans, rivers and lakes
	Eutrophication	Excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which causes a dense growth of plant life and death of animal life from lack of oxygen
	Eco-toxicity	Potential for biological, chemical or physical stressors to affect ecosystems.
Social	Carcinogenic	Environmental emissions that are directly linked to causing cancer.
	Non Carcinogenic	Toxic emissions that are not linked to cancer causing pathogens.
	Respiratory Effects	Environmental emissions that directly result in respiratory conditions and diseases such as cancer.

Table 9: Geometric mean of environmental impact assessment using AHP analysis

		1	2	3	4	5	6	**Geometric Mean**	**Criteria Weights**
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1.00	0.27	1.20	0.71	0.82	0.59	0.69	9.62%
2	Global Warming	3.77	1.00	5.30	3.00	4.40	2.71	2.99	41.56%
3	Smog	0.83	0.19	1.00	0.49	0.88	0.59	0.59	8.15%
4	Acidification	1.40	0.33	2.02	1.00	2.11	1.06	1.13	15.75%
5	Eutrophication	1.22	0.23	1.14	0.47	1.00	0.38	0.62	8.62%
6	Eco-toxicity	1.68	0.37	1.68	0.95	2.63	1.00	1.17	16.30%
							Total	7.19	100.00%

Consistency Index	0.012
Random Index	1.240
Consistency Ratio	0.009

Table 9: Geometric mean of social impact assessment using AHP analysis

		1	2	3	**Geometric Mean**	**Criteria Weights**
		Carcinogenic	Non Carcinogenic	Respiratory Effects		
1	Carcinogenic	1.00	3.50	1.73	1.82	54.08%
2	Non Carcinogenic	0.29	1.00	0.58	0.55	16.27%
3	Respiratory Effects	0.58	1.73	1.00	1.00	29.66%
				Total	3.37	100%

Consistency Index	0.00132
Random Index	0.58
Consistency Ratio	0.0023

6.3: Step 3 | Analyze Alternatives

- Economic Alternative Analysis

As defined earlier the Economic pillar of sustainability includes not only a concern for cost but the overall quality of the product must be considered. Due to the strict specification requirements associated with large fiber contracts, the quality of the plastics involved in this study were assumed to be equal.

The economic cost data was obtained through the analysis of purchasing order spreadsheet from a contract negotiation between a large telecommunications provider and a fiber optic cabling manufacturer. Due to the sensitivity of continual contract negotiations as well as corporate policy this information, in its entirety, cannot be published. Table 11 below lists the price per foot of each cable with a jacket made primarily of HDPE, PET, and PVC.

Table 11: Raw cost data ($/Ft)

	Cost
HD-Polyethylene	$ 0.5025
Polyethylene Terephthalate	$ 0.4840
Polyvinyl Chloride	$ 0.4762

The costs were then analyzed in an AHP matrix in order to rate them against each other and to determine a normalized score (Table 12). In order to account for the lowest price being of the most optimal value, each PWC score was inverted. Once this was calculated, PVC was delineated as the most optimal cable with regards to price, which falls in line with its cost per foot.

Table 12: Economic scores (cost)

COST	HDPE	PET	PVC	Geometric Mean	Normalized Weights	Criteria Weights
HDPE	1.000	0.963	0.948	0.9700	0.3233	32.33%
PET	1.038	1.000	0.984	1.0071	0.3356	33.56%
PVC	1.055	1.016	1.000	1.0237	0.3411	34.11%
			Total	3.0008	1	100%

❖ Environmental Alternative Analysis

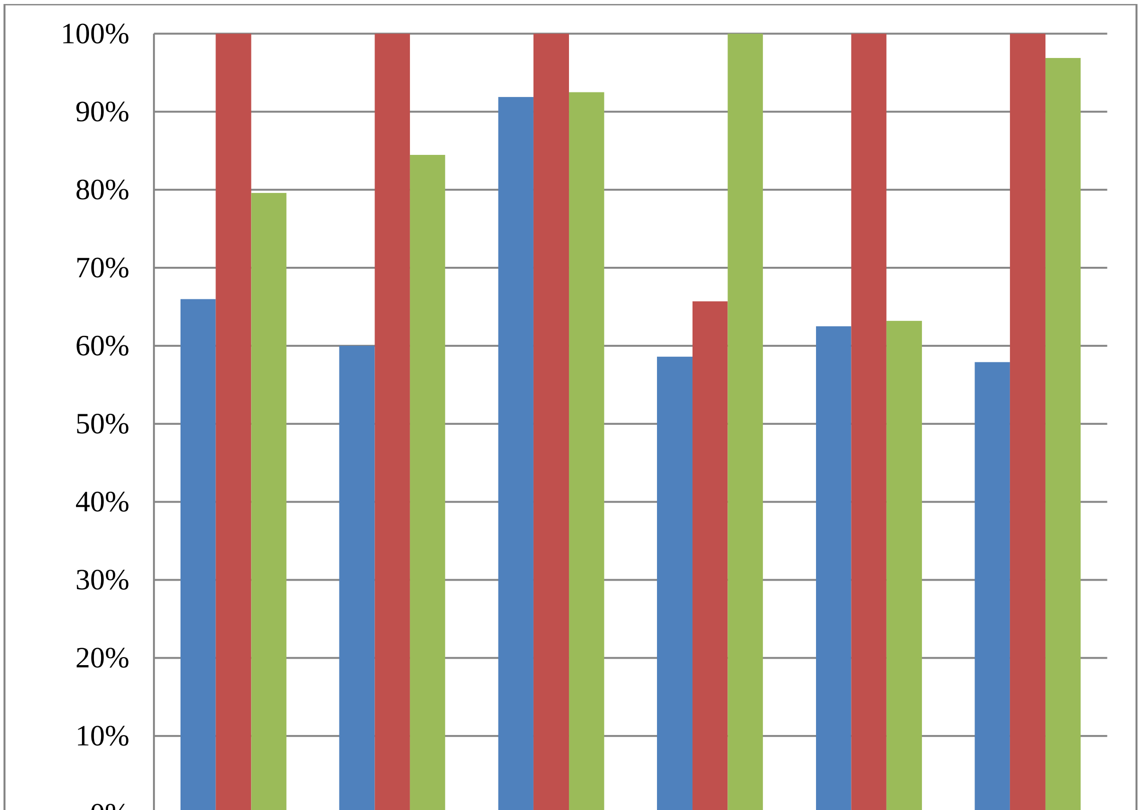
Once the plastics were defined, SimaPro 8 software was used to create a simulation based off of the impact these plastics would have on the environment using the TRACI tool discussed earlier. Table 13 below shows the raw data performance by each alternative in the respective Environmental criteria.

Table 13: Raw data for environmental impact factors based on TRACI LCA analysis

TRACI IMPACT CATEGORIES	HDPE	PET	PVC	Unit
Ozone Depletion	3.12E-07	4.73E-07	3.77E-07	kg CFC-11
Global Warming	3.510	5.850	4.950	kg CO2
Smog	0.296	0.322	0.298	kg O3
Acidification	1.270	1.420	2.160	mol H+
Eutrophication	0.0111	0.0177	0.0112	kg N
Eco-toxicity	6.350	11.00	10.60	CTUe

These results below provide a basic view of how the cables rank against each other. As illustrated in Table 13, each cable's performance in each of the TRACI impact categories was varying. Of the six TRACI impact categories covered by the Environmental Criteria, the production of fiber optic cabling contributed extensively in the release of byproducts that affected Eco-Toxicity, Global Warming and Acidification the most.

Due to the varying range of outputs in each category, the data was transformed in to % points in order to establish a common metric. The data in Figure 15 allows for analysis of each cable rated against each other based on the greatest contributor being set at 100% and the remaining as a percentage of the greatest output. For example, PET produces the greatest effect on Ozone Depletion while PVC and PE contribute roughly 80% and 66% of PET's output.



	Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Ecotoxicity
HDPE	66%	60%	92%	59%	63%	58%
PET	100%	100%	100%	66%	100%	100%
PVC	80%	85%	93%	100%	63%	97%

Figure 15: Normalized data for environmental impact factors based on TRACI LCA analysis

SimaPro presented the most negative impacting categories at 100%; the remaining scores were presented as a percentage of the leading score. By taking the inverse of the data in Table 13, the Impact Data could now be presented in a more intuitive manner. This transformed data allowed for the categories receiving the lowest TRACI Impact Scores to be shown as the most beneficial with the highest % Fiber Score (Table 14).

Table 14: Inversed and normalized data for environmental impact factors based on TRACI LCA analysis

TRACI IMPACT CATEGORIES	HDPE	PET	PVC
Ozone Depletion	1.52	1.00	1.26
Global Warming	1.67	1.00	1.18
Smog	1.09	1.00	1.08
Acidification	1.71	1.52	1.00
Eutrophication	1.60	1.00	1.58
Eco-toxicity	1.73	1.00	1.03

This inversed data was then run through a PWC table in order to define the % Fiber Score for each Cable Alternative with respect to each TRACI Environmental Factor, shown in Table 15.

Table 15: Comparison of fiber alternatives with respect to TRACI environmental factors (A. Ozone Depletion, B. Global Warming, C. Smog, D. Acidification, E. Eutrophication, F. Eco-toxicity)

A: Ozone Depletion

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.515	1.206	1.2226	0.4017	40%
PET	0.660	1.000	0.796	0.8069	0.2652	27%
PVC	0.829	1.256	1.000	1.0137	0.3331	33%
			TOTAL	3.0432	1	100%

B: Global Warming

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.667	1.408	1.3290	0.4329	43%
PET	0.600	1.000	0.845	0.7974	0.2597	26%
PVC	0.710	1.183	1.000	0.9437	0.3074	31%
			TOTAL	3.0700	1	100%

C: Smog

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.088	1.007	1.0308	0.3433	34%
PET	0.919	1.000	0.925	0.9473	0.3155	32%
PVC	0.994	1.081	1.000	1.0241	0.3411	34%
			TOTAL	3.0022	1	100%

D: Acidification

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.121	1.706	1.2414	0.4036	40%
PET	0.892	1.000	1.522	1.1073	0.3600	36%
PVC	0.586	0.657	1.000	0.7275	0.2365	24%
			TOTAL	3.0762	1	100%

E. Eutrophication

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.600	1.011	1.1740	0.3826	38%
PET	0.625	1.000	0.632	0.7337	0.2391	24%
PVC	0.989	1.582	1.000	1.1610	0.3783	38%
			TOTAL	3.0686	1	100%

F. Eco-toxicity

	HDPE	PET	PVC	Geometric Mean	Normalized Fiber Scores	% Fiber Scores
HDPE	1.000	1.727	1.674	1.4245	0.4594	46%
PET	0.579	1.000	0.969	0.8248	0.2660	27%
PVC	0.598	1.032	1.000	0.8512	0.2745	27%
			TOTAL	3.1004	1	100%

The data from Table 15 was then merged with the Impact Assessment provided by the industry experts, seen in Table 9, in order to provide some quantitative data for each impact category. Table 16 on the following page demonstrates how these tables were merged for each TRACI impact category included in the Environmental Analysis. The Weighted Fiber Score for each plastic was then summed to give an overall Environmental Analysis Score.

Table 16: Computation of weighted fiber scores for each TRACI environmental impact factor (A. Ozone Depletion, B. Global Warming, C. Smog, D. Acidification, E. Eutrophication, F. Eco-toxicity)

A: Ozone Depletion			
	% Fiber Scores	Criteria Weights	Weighted Fiber Score
HDPE	40%	9.62%	0.03866
PET	27%		0.02551
PVC	33%		0.03205
	100%		

B: Global Warming			
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	43%	41.56%	0.17993
PET	26%		0.10796
PVC	31%		0.12776
	100%		

C: Smog			
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	34%	8.15%	0.02799
PET	32%		0.02572
PVC	34%		0.02781
	100%		

D: Acidification			
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	40%	15.75%	0.06355
PET	36%		0.05668
PVC	24%		0.03724
	100%		

E. Eutrophication			
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	38%	8.62%	0.03297
PET	24%		0.02061
PVC	38%		0.03260
	100%		

F. Eco-toxicity			
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	46%	16.30%	0.07487
PET	27%		0.04335
PVC	27%		0.04474
	100%		

Figure 16 below provides the total environmental scores, which were tabulated by summing the Weighted Final Scores of each plastic alternative for each Environmental Criteria. HDPE is decidedly the least environmentally impacting plastic currently being used in fiber optic cable jacketing.

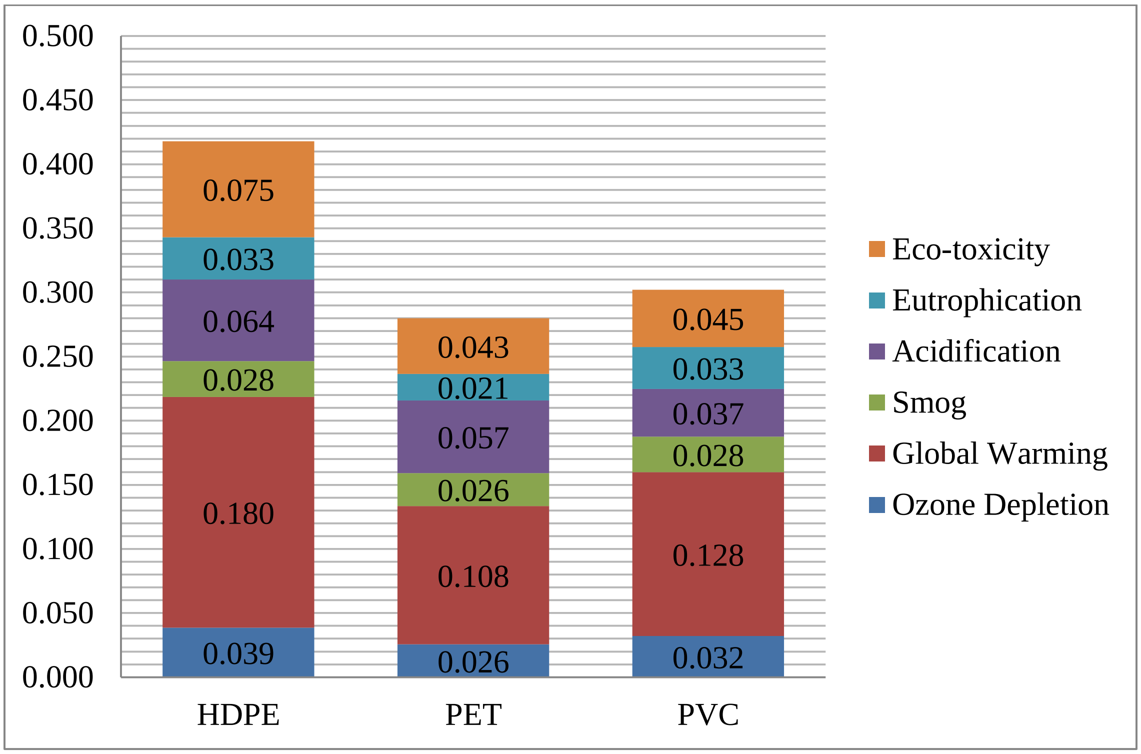


Figure 16: Total environmental score for each fiber optic alternative based on TRACI LCA analysis

❖ Social Alternative Analysis

The Social Alternative Analysis was calculated by the same method as the Environmental Alternative Analysis, merging SimaPro Software Data with the AHP weighting provided by an Environmental Health and Safety Industry Expert.

Table 17 below provides the raw data scores for the Social Criteria for each Fiber Alternative. As you can see each plastic carried extensive weight with regards to Respiratory Effects. In order to balance these scores and provide more accurate view of the data, each criterion was transformed in to a percentage point based off the most impacting plastic. This transformed data can be found in Figure 17.

Table 17: TRACI social impact factor for each fiber alternative

IMPACT FACTOR	HDPE	PET	PVC	
Carcinogenic	2.92E-07	3.58E-07	2.18E-07	CTUh
Non Carcinogenic	1.00E-06	1.36E-06	1.39E-06	CTUh
Respiratory Effects	0.004560	0.006050	0.007560	kg PM10

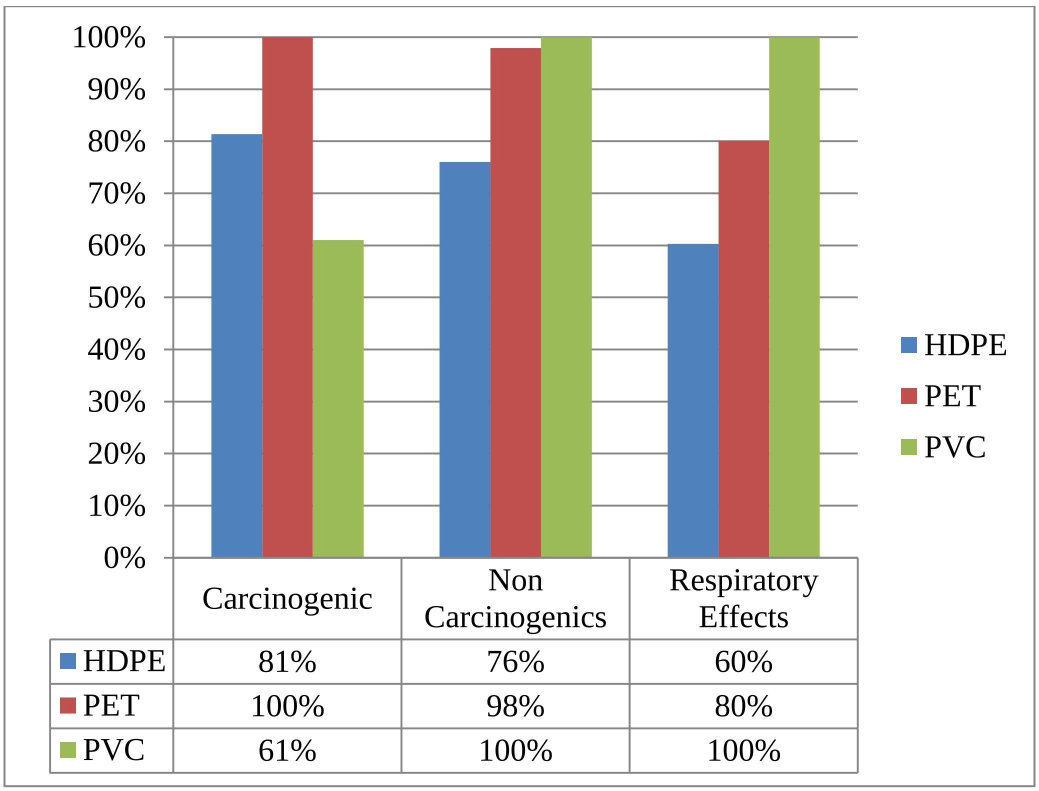


Figure 17: Normalized TRACI social impact factor scores for each fiber alternative

As discussed earlier with the Environmental Criteria Analysis, this Impact Data provides a view of the most impacting alternative in each criterion. For example, Polyethylene Terephthalate produces the most Carcinogenic byproducts during cable production, therefor producing a 100% score. Following the method used for the Environmental Data Analysis this data was inversed, allowing the least impactful

Alternative in each Social Criteria to receive the highest score. This transformation can be seen in Table 18 below.

Table 18: Inversed TRACI social impact data for each fiber alternative

SOCIAL/HEALTH & SAFETY CRITERIA	HDPE	PET	PVC
Carcinogenic	1.23	1.00	1.64
Non Carcinogenic	1.32	1.02	1.00
Respiratory Effects	1.66	1.25	1.00

Table 19 provides the calculations that were conducted in order to obtain the % Fiber Scores required for the Social Criteria for each plastic alternative.

Table 19: Comparison of fiber alternatives with respect to TRACI social factors (A. Carcinogenic, B. Non Carcinogenic, C. Respiratory Effects)

A: Carcinogenic

	HDPE	PET	PVC	Geometric Mean	Normalized Weights	% Fiber Scores
HDPE	1.000	1.229	0.749	0.9728	0.3176	32%
PET	0.814	1.000	0.610	0.7919	0.2585	26%
PVC	1.334	1.639	1.000	1.2981	0.4238	42%
			TOTAL	3.0628	1	100%

B: Non Carcinogenic

	HDPE	PET	PVC	Geometric Mean	Normalized Weights	% Fiber Scores
HDPE	1.000	1.288	1.316	1.1923	0.3943	39%
PET	0.776	1.000	1.021	0.9256	0.3061	31%
PVC	0.760	0.979	1.000	0.9061	0.2996	30%
			TOTAL	3.0240	1	100%

C: Respiratory Effects

	HDPE	PET	PVC	Geometric Mean	Normalized Weights	% Fiber Scores
HDPE	1.000	1.328	1.658	1.3012	0.4245	42%
PET	0.753	1.000	1.248	0.9795	0.3196	32%
PVC	0.603	0.801	1.000	0.7846	0.2560	26%
			TOTAL	3.0653	1	100%

Once again the % Fiber Scores were combined with the Criteria Weights delivered by the industry expert in Table 10, providing a Weighted Final Score for each plastic alternative in each Social criterion. Table 20 and Figure 18 depict these computations.

Table 20: Computation of weighted fiber scores for each TRACI social impact factor (A. Carcinogenic, B. Non Carcinogenic, C. Respiratory Effects)

A: Carcinogenic			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	32%	54.08%	0.17176
PET	26%		0.13981
PVC	42%		0.22919
TOTAL	100%		
B: Non Carcinogenic			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	39%	16.27%	0.06413
PET	31%		0.04979
PVC	30%		0.04874
TOTAL	100%		
C: Respiratory Effects			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	42%	29.66%	0.12589
PET	32%		0.09477
PVC	26%		0.07591
TOTAL	100%		

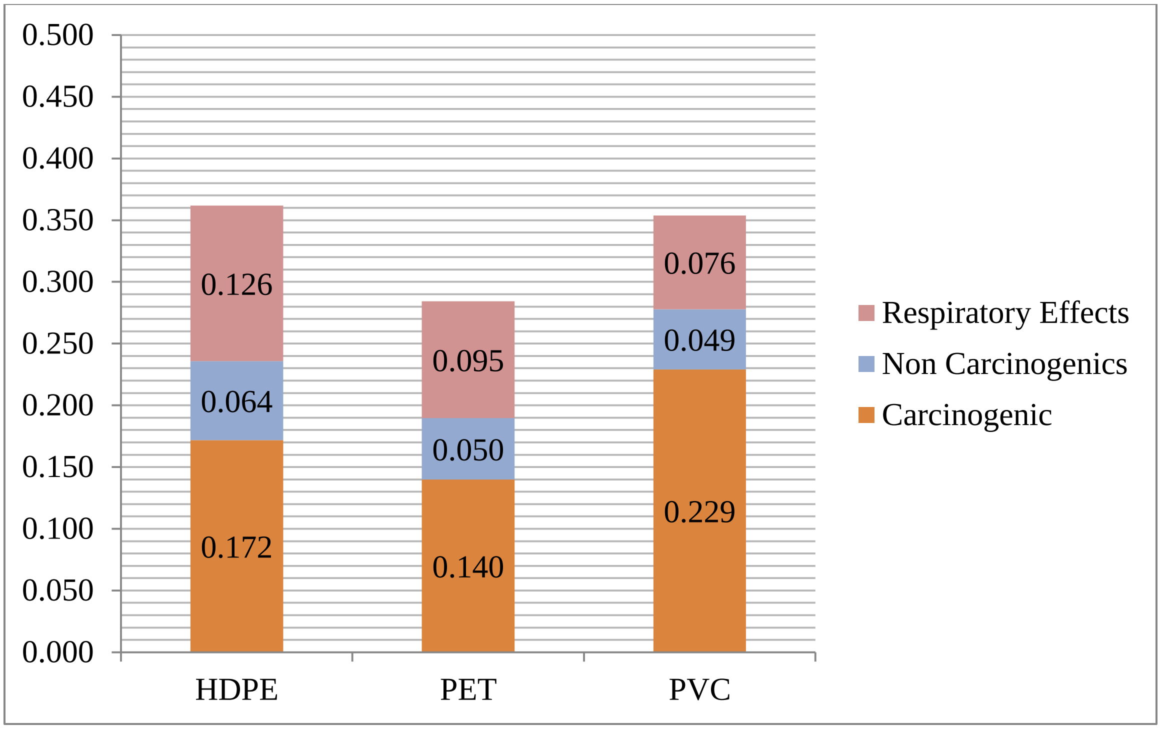
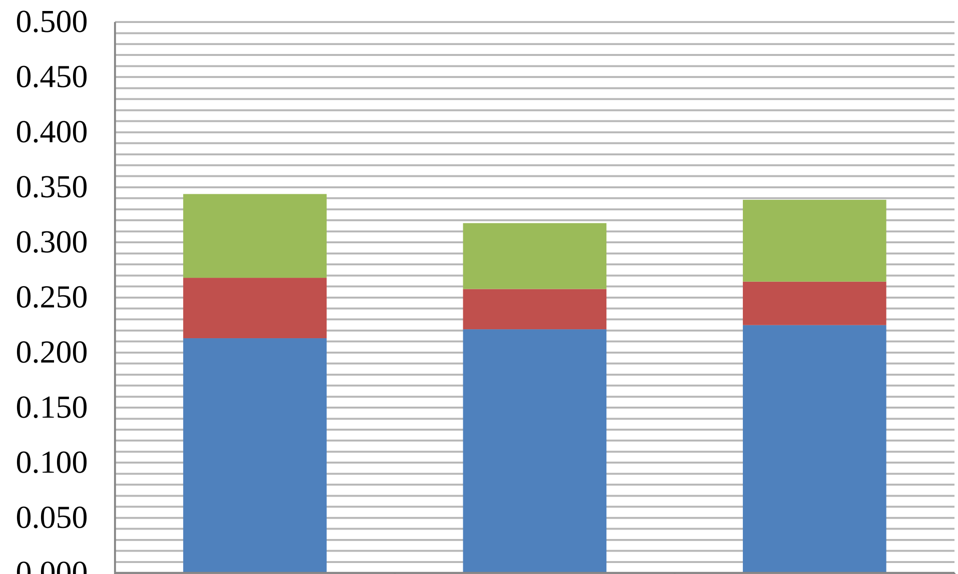


Figure 18: Total social score for each fiber optic alternative based on TRACI LCA analysis

6.4: Step 4 | Select Best Alternative

Once the final scores were tabulated for each of the three pillars of sustainability, one final merger was required to tie each criteria score together, to produce a Final Green Purchasing Score for each cable based on the data provided. Figure 19 below, demonstrates that with the current purchasing concentrations provided by the procurement experts at the ISP, HD-Polyethylene is the most appropriate exterior jacketing material followed closely by Polyvinyl Chloride.



	HDPE	PET	PVC
Social	0.0760	0.0597	0.0743
Environmental	0.0547	0.0367	0.0396
Economic	0.2130	0.2212	0.2248

Figure 19: Final purchasing suggestion using initial criteria weights

CHAPTER 7: SENSITIVITY ANALYSIS | CRITERIA WEIGHTS

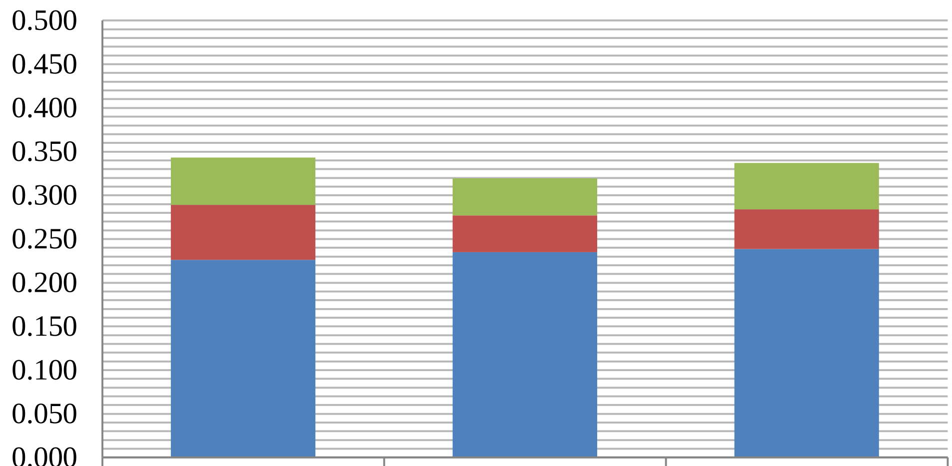
Preliminary conclusions from the initial data sets confirmed that the telecommunications provider should alter its current purchasing pattern of ordering the bulk of its fiber with an exterior sheathing in Polyvinyl Chloride, shifting to the more sustainable HD-Polyethylene. In order to account for potential fluctuations on purchasing habits and opinions and validate the initial purchasing decision findings, a review was conducted of various weighting alterations based on the purchasing suggestion associated with those weights.

❖ Economically Centered

In order to place a greater emphasis on cost savings, certain purchasing experts may place a greater emphasis on the economic security of the company. In order to account for this potential circumstance the purchasing weights were skewed in that direction. Table 21 below provides the updated purchasing weights in this example.

Table 21: Economically centered weighting

Criteria	Avg. Weight
Economical	70%
Environmental	15%
Social	15%



	HDPE	PET	PVC
Social	0.0543	0.0427	0.0531
Environmental	0.0627	0.0420	0.0453
Economic	0.2263	0.2349	0.2388

Figure 20: Green purchasing graph | economically centered

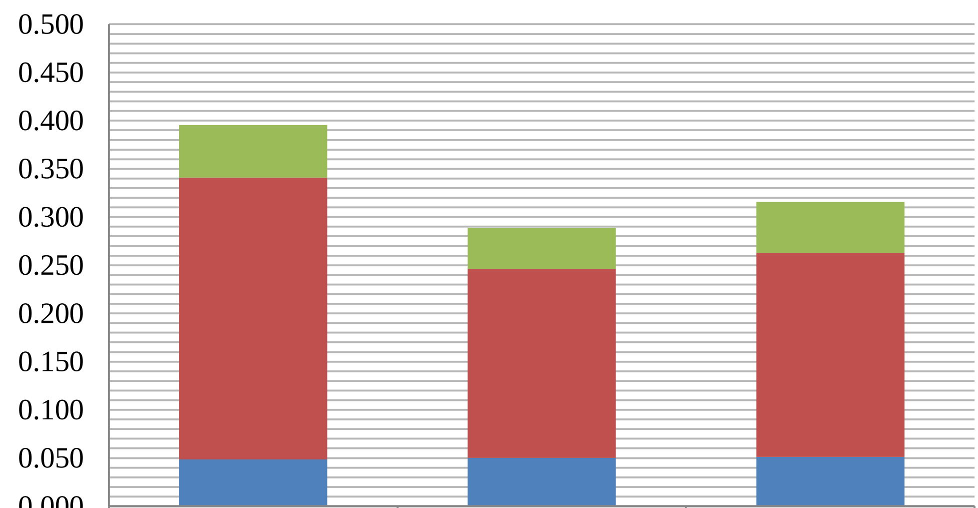
As depicted in the Figure 20 the heavier weighting on the economic pillar further strengthen the initial purchasing decision, which is to procure fiber optic cables with jackets comprised of HD-Polyethylene. However, this contradicts the intuitive logic one can deduce from Table 11, which clearly shows that HD-Polyethylene is by far the most expensive alternative. This provides further evidence that supports the notion that although the cheapest plastic alternative may be more attractive, when consideration, even in the slightest, is placed on the Environmental and Social Sustainability of this decision, a radically different jacketing material might become evident.

❖ Environmentally Centered

The data in Table 7 clearly indicated upfront that little to no attention was given to the Environmental pillar of sustainability. Obtaining only a geometric average weighting of 13.1%, there clearly is room for improvement. As shown above in the Economically Centered purchasing decision analysis, there was little to no movement among the jacketing materials when just a few points were added to the environmental criteria, which underline the overall dominance of HD-Polyethylene. Table 22 and Figure 21 below provide an alternative weighting and the resulting scores when even greater emphasis is placed on the environmental impact of the fiber optic cable jacketing.

Table 22: Environmentally centered weighting

Criteria	Avg. Weight
Economical	15%
Environmental	70%
Social	15%



	HDPE	PET	PVC
Social	0.0543	0.0427	0.0531
Environmental	0.2926	0.1959	0.2115
Economic	0.0485	0.0503	0.0512

Figure 21: Green purchasing graph | environmentally centered

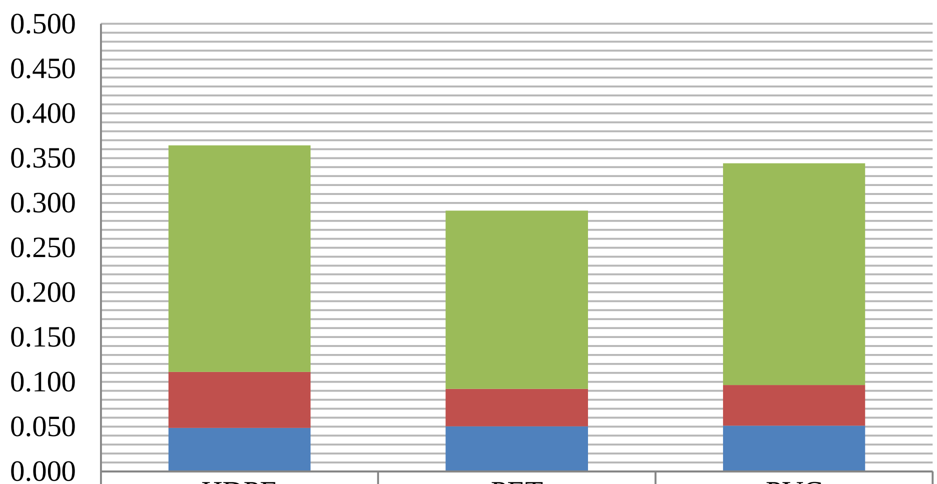
When greater emphasis is placed on the environmental pillar of sustainability, a dramatic change occurs with the fiber optic purchasing suggestion. HD-Polyethylene is now overwhelmingly the most appropriate material to be used in the exterior jacketing of fiber optic cabling. Prior to this emphasis on an environmentally centered decision, PVC and PET closely followed HDPE, however this clearly indicates that no matter the price HDPE will always remain the more environmentally responsible suggestion.

❖ Socially Centered

The initial geometric average weightings shown in Table 7 provided by the purchasing experts at the ISP had placed a reasonable 21.0% weighting on the Social Criteria of sustainability, lending understandable concern to the potential cancerous and respiratory effects certain plastics can have on society. This provided a purchasing strategy that pushed for HDPE based fiber optic cables.

Table 23: Socially centered weighting

Criteria	Avg. Weight
Economical	15%
Environmental	15%
Social	70%



	HDPE	PET	PVC
Social	0.2532	0.1991	0.2477
Environmental	0.0627	0.0420	0.0453
Economic	0.0485	0.0503	0.0512

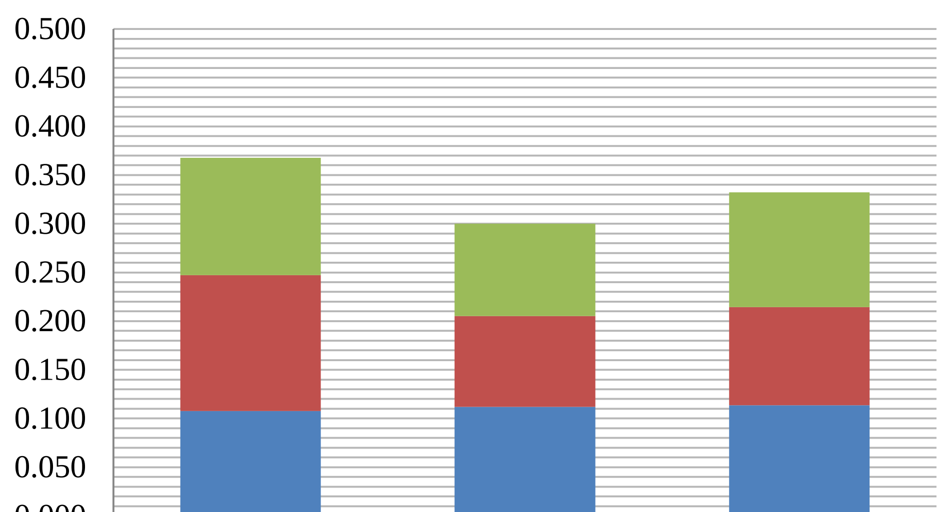
Figure 22: Green purchasing graph | socially centered

❖ Centered and Validation

By showing an emphasis on each criterion, the data suggested that perhaps HDPE was the most appropriate fiber purchasing suggestion regardless of which criteria was emphasized. In order to gain a greater understanding of just how skewed the initial findings were, the data was re-analyzed with equal weightings between all criteria. The following Tables and Figures depict the results of this.

Table 24: Centered weighting

Criteria	Avg. Weight
Economical	33%
Environmental	33%
Social	33%



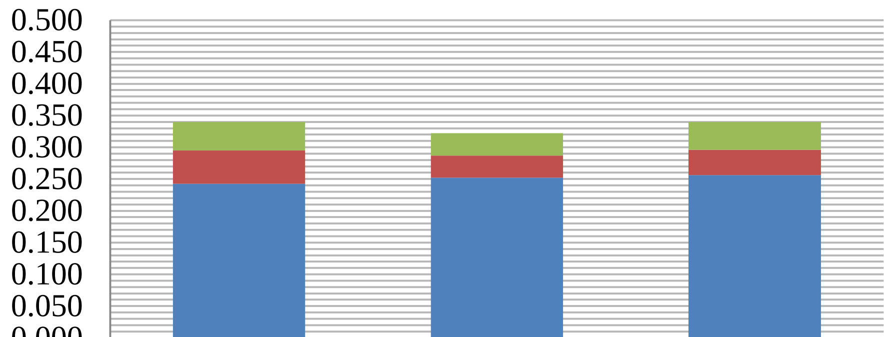
	HDPE	PET	PVC
Social	0.1206	0.0948	0.1179
Environmental	0.1393	0.0933	0.1007
Economic	0.1078	0.1119	0.1137

Figure 23: Green purchasing graph | centered

As Figure 23 shows, when placing an equal emphasis on all criteria, HDPE again was the most optimum procurement suggestion. Further analysis was conducted to find the exact weighting required to validate the telecommunications provider's current purchasing strategy that focuses the majority of its cable asset allocation on fiber with jacketing made nearly entirely of Polyvinyl Chloride. Due to the ISP's already overwhelming emphasis on the price of the cable, this Validation Weighting was accomplished by incrementally adding percentage points to the Economic Criteria while attempting to keep the Environmental and Social strategies equal. After some balancing, PVC finally overtook HDPE as the more sustainable option when 75.1% of the weighting was placed on an Economical concern while Environmental and Social standards were limited to 12.45%, as it is shown in Table 25 and Figure 24.

Table 25: Validation weighting

Criteria	Avg. Weight
Economical	75.10%
Environmental	12.45%
Social	12.45%



	HDPE	PET	PVC
Social	0.0450	0.0354	0.0441
Environmental	0.0520	0.0348	0.0396
Economic	0.2428	0.2520	0.2562

Figure 24: Green purchasing graph | validation

CHAPTER 8: SENSITIVITY ANALYSIS | ENVIRONMENTAL WEIGHTS

While analyzing the impact of various pillar weights, interest arose over the potential impact of varying the LCA weights that were provided by Environmental Experts. Therefor a second Sensitivity Analysis was included which would account for the fact that only four experts were used in this experiment. The following are various weighting schemes to test the validity of the environmental assessment utilizing the initial weights provided by the purchasing experts.

- Equal Environmental LCA Weighting

By leveling all of the TRACI Impact weights established in the initial Environmental LCA AHP matrix provided by the environmental and sustainability industry experts, the plastic jacketing alternatives were essentially scored solely by their performance in the SimaPro8 software. With six criteria, each TRACI category received 16.67 percent of the final weight. Table 26 and 27 below provides this breakdown. Figure 25 provides the final scores for each plastic alternative within the Environmental pillar of sustainability, as should be expected, given the initial purchasing weighting provided by the procurement experts, PVC delineates itself as the most sustainable option due to the heavy weighting placed on the economic and social pillars where it greatly outperforms both HDPE and PET.

Table 26: Computation of weighted fiber scores for each TRACI environmental impact factor with equal criteria weights (A. Ozone Depletion, B. Global Warming, C. Smog, D. Acidification, E. Eutrophication, F. Eco-toxicity)

A: Ozone Depletion

	% Fiber Scores	Criteria Weights	Weighted Fiber Score
HDPE	40%		0.066957
PET	27%	16.67%	0.044192
PVC	33%		0.055517
	100%		

B: Global Warming

	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	43%		0.072148
PET	26%	16.67%	0.043289
PVC	31%		0.051230
	100%		

C: Smog

	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	34%		0.057224
PET	32%	16.67%	0.052589
PVC	34%		0.056853
	100%		

D: Acidification

	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	40%		0.067260
PET	36%	16.67%	0.059992
PVC	24%		0.039415
	100%		

E. Eutrophication

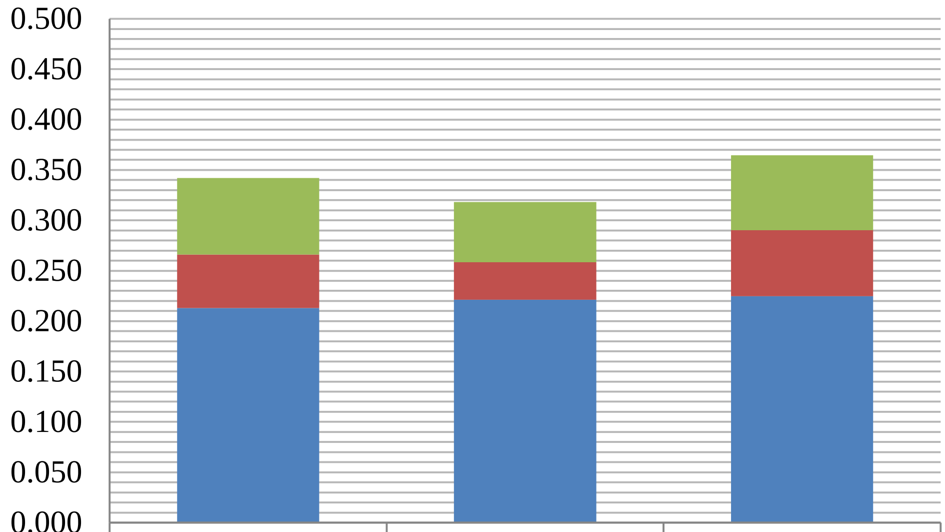
	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	38%		0.063761
PET	24%	16.67%	0.039851
PVC	38%		0.063055
	100%		

F. Eco-toxicity

	% Fiber Scores	Criteria Weights	Weighted Final Score
HDPE	46%		0.076575
PET	27%	16.67%	0.044337
PVC	27%		0.045755
	100%		

Table 27: Computational of total environmental score for fiber optic alternative with equal criteria weights

ENVIRONMENTAL SCORE	HDPE	PET	PVC
Ozone Depletion	0.066957	0.044192	0.055517
Global Warming	0.072148	0.043289	0.051230
Smog	0.057224	0.052589	0.056853
Acidification	0.067260	0.059992	0.039415
Eutrophication	0.063761	0.039851	0.063055
Eco-toxicity	0.076575	0.044337	0.045755
	0.403926	0.284249	0.311825



	HDPE	PET	PVC
Social	0.0760	0.0597	0.0743
Environmental	0.0529	0.0372	0.0655
Economic	0.2130	0.2212	0.2248

Figure 25: Green purchasing graph | equal environmental LCA weights

- Equal Social LCA Weighting

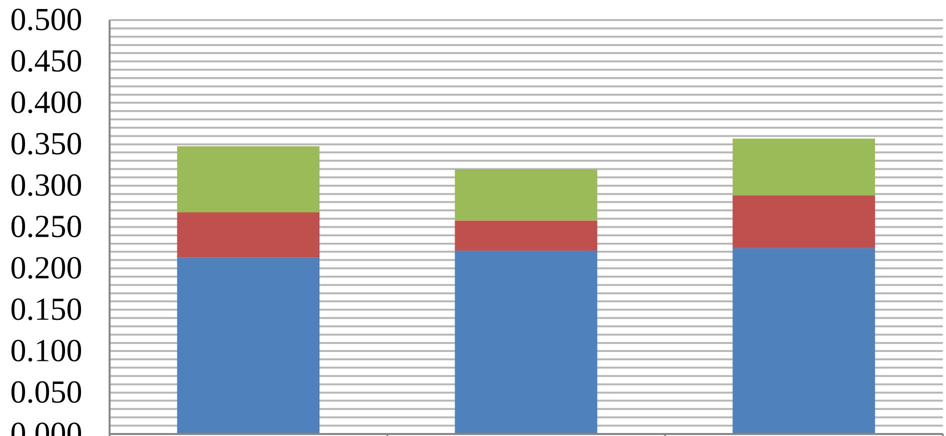
Following the same methodology used to level the Environmental LCA weighting, the Social TRACI Impact categories were transformed to verify the validity of the industry expert's suggestions. Using the same initial purchasing weights provided by the large telecommunications provider purchasing experts, each of the Social impact categories received a 33.33% rating as shown in Table 28 below. Figure 26 provides the final Social LCA Scores once the LCA weighting provided by the industry experts were leveled. Once again, PVC is the most socially responsible jacketing material in this scenario, based on the initial purchasing weighting provided by the purchasing experts, lending further validity to the model produced. This result as with the level environmental scenario lend to the importance of the PWC completed by the environmental and sustainability industry experts.

Table 28: Computation of weighted fiber scores for each TRACI social impact factor with equal criteria weights (A. Carcinogenic, B. Non Carcinogenic, C. Respiratory Effects)

A: Carcinogenic			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	32%	33.33%	0.105873
PET	26%		0.086181
PVC	42%		0.141280
TOTAL	100%		
B: Non Carcinogenic			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	39%	33.33%	0.131425
PET	31%		0.102025
PVC	30%		0.099883
TOTAL	100%		
C: Respiratory Effects			
	Fiber Score	Criteria Weights	Weighted Final Score
HDPE	42%	33.33%	0.141494
PET	32%		0.106518
PVC	26%		0.085321
TOTAL	100%		

Table 29: Computational of total social score for fiber optic alternative with equal criteria weights

SOCIAL SCORE	HDPE	PET	PVC
Carcinogenic	0.105873	0.086181	0.141280
Non Carcinogenic	0.131425	0.102025	0.099883
Respiratory Effects	0.141494	0.106518	0.085321
	0.378792	0.294724	0.326484



	HDPE	PET	PVC
Social	0.0795	0.0619	0.0686
Environmental	0.0547	0.0367	0.0635
Economic	0.2130	0.2212	0.2248

Figure 26: Green purchasing graph | equal social LCA weights

By transforming not only the Environmental but the Social LCA AHP weighting provided by the environmental and sustainability industry experts, this paper was able to prove that the model is consistent, and that proper weighting by procurement experts can solely dictate the outcome of the fiber purchasing suggestion. Furthermore, this sensitivity analysis proves that PWCs conducted by the industry experts are valid, necessary and consistent.

CHAPTER 9: IMPACT ANALYSIS

While there are only three alternative jacketing options in this study, there are a multitude of potential areas where these decisions will be felt. Below there is a breakdown between categories to provide further analysis in these areas.

❖ Economic Impact Analysis

While still assuming that the overall quality of the product will remain constant, economically speaking the large telecommunications provider is due to feel some impact financially through its fiber optic purchasing selection. While HDPE and PET are a bit more expensive at $.5025 and $.4840 respectively, the telecom company currently sources a majority of its cable with an exterior jacketing of PVC running them $.4762 per foot.

Table 30: Impact analysis | economic for North and South Carolina

	Cost per Foot	Feet of Cable	Total Fiber Cost	Change in Cost
HDPE	$ 0.5025	7,526,458	$3,782,116.26	$198,148.13
PET	$ 0.4840	7,526,458	$3,642,937.12	$58,968.98
PVC	$ 0.4762	7,526,458	$3,583,968.14	$0.00

A recent Carolinas Market Review by the Construction Department within this provider detailed the use of roughly 1,425 miles of fiber optic cable, or 7.5 million feet of cable in a single year for North and South Carolina. By shifting its purchasing decision from PVC to HDPE based on the sustainability research published in this study, the large ISP could incur an increase in yearly costs by roughly $198,000 for this one region.

The Carolina Market discussed earlier, which includes North and South Carolina, only accounted for 17.78% of this company's yearly business in 2014. If this math was applied to the company as a whole this ISP would face an increase in cost of $1.11 Million in fiscal 2014.

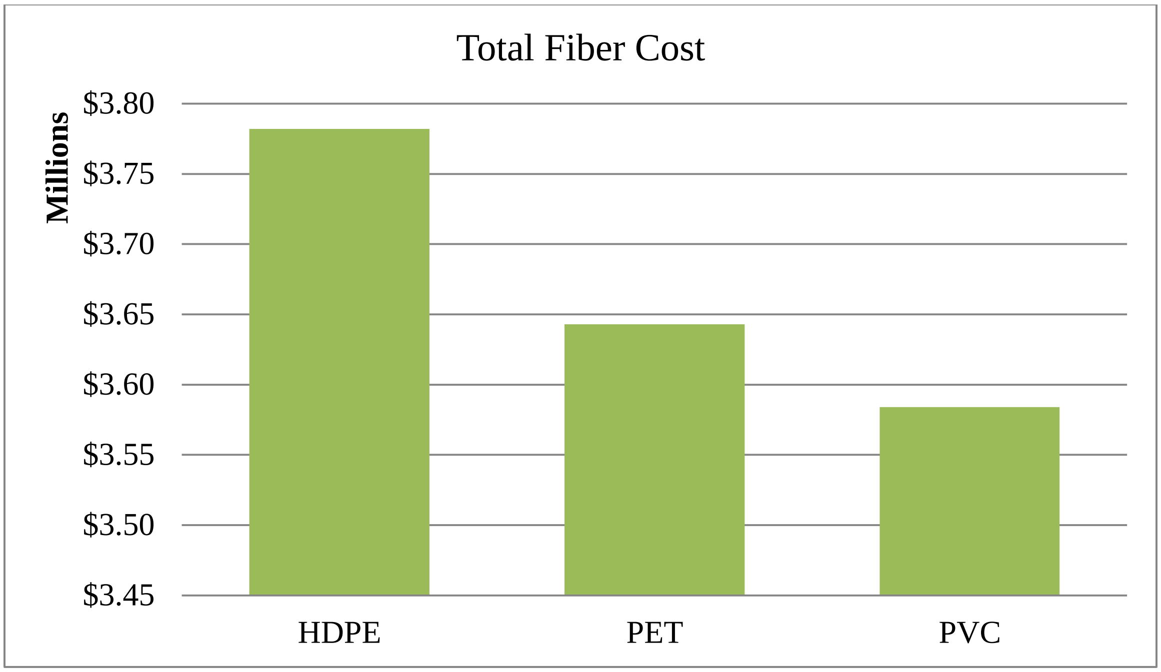


Figure 27: economic impact analysis for alternative purchasing strategy in North and South Carolina

❖ Environmental Impact Analysis

The environmental impact of switching from PVC to HDPE will most definitely be felt within the confines of the LCA data provided in this research. By purchasing HDPE rather than PVC, the telecom provider will be reducing the carbon emissions that lead directly to global warming by 1.44kg CO_2/ kg of Fiber produced. Putting this in perspective, fiber optic cable can come in varying weights, ranging from 145kg /km (98lbs/1000ft) to 283kg/km (190lbs/1000ft), which means that for every km of fiber that is switched from PVC to HDPE, this telecom provider is reducing carbon emissions linked to global warming by considerable amounts, somewhere between 208.8kg CO2 and 407.52kg CO2.

Using the information provided by the Carolinas Market construction budget, the provider used 2294 (1425mi) of fiber optic cable last year comprising a weight range between 332,630 – 649,202kg. Simple arithmetic finds that if this cable was entirely PVC and had been switched to entirely HDPE, this telecom provider would have reduced its total carbon emissions linked to global warming for the North and South Carolina market an average of 1,621 Million kg CO2 in fiscal 2014. According to the EPA (2015) a typical passenger car will produce nearly 8.89 kg CO2 per gallon of gas or 411 grams per mile, equating to roughly 4.75 metric tons of CO2 per year. Had this ISP switched from PVC to entirely HDPE in Fiscal 2014, this would have equated to taking an average of 341,400 cars off of the road in fiscal 2014. When considering this on a country wide scale, this ISP would effectively be taking 1.92 Million cars off of the road in just fiscal 2014

Table 31: Global warming impact analysis data for North and South Carolina

	kg CO2	Fiber Distance (km)	Fiber Weight - Low	Fiber Weight - High	Fiber Weight - Avg	kg CO2 (Low)	kg CO2 (High)	kg CO2 (Avg)
HDPE	3.510	2294	332,630	649,202	490,916	2.678E+09	5.227E+09	3.953E+09
PET	5.850	2294	332,630	649,202	490,916	4.464E+09	8.712E+09	6.588E+09
PVC	4.950	2294	332,630	649,202	490,916	3.777E+09	7.372E+09	5.574E+09

Table 32: Yearly auto impact analysis for North and South Carolina

Average	Millions kg CO2	Change in Millions kg CO2	Auto Output (Kg Co2/yr.)	Cars
HDPE	3,952.82	1,621.67	4750.00	(341,404)
PET	6,588.04	(1,013.54)	4750.00	213,377
PVC	5,574.49	-	4750.00	-

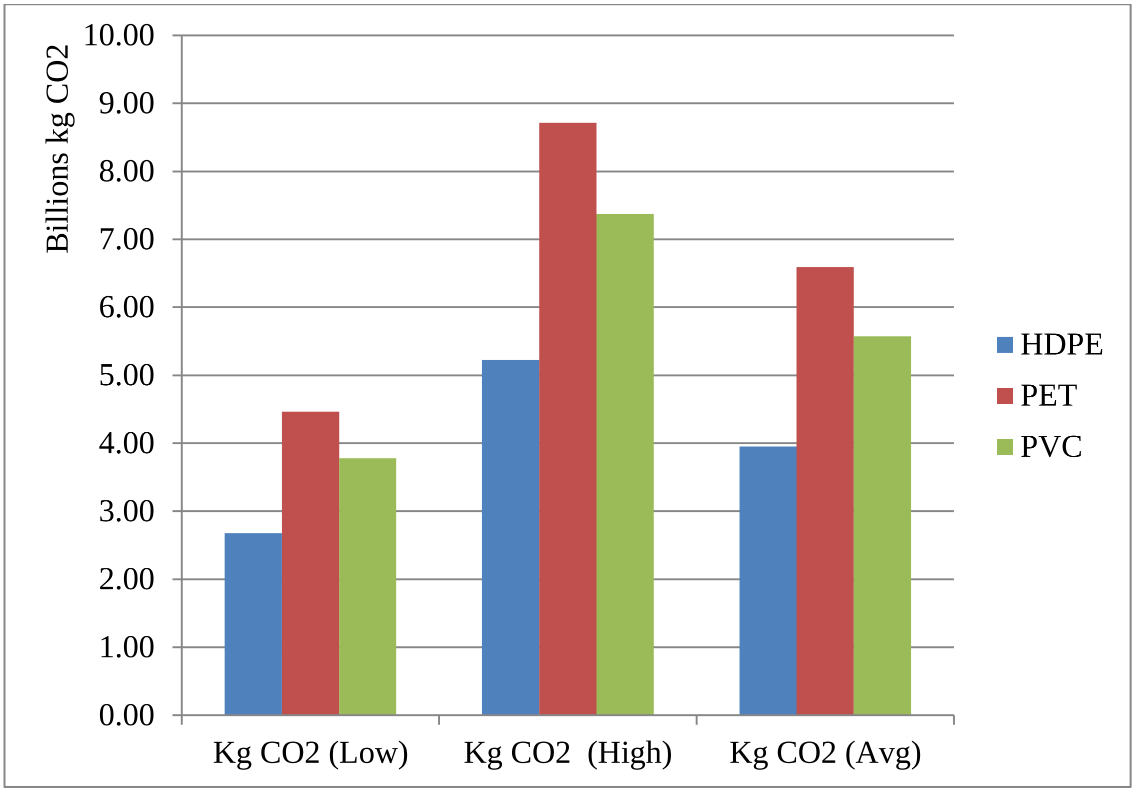


Figure 28: Environmental impact analysis based on global warming data for North and South Carolina

- Social Impact Analysis

The potential Social Impact of switching from PVC to HDPE was also felt within the confines of the Respiratory Effects provided by the LCA provided in this research. By purchasing HDPE rather than PVC, this telecom provider can drastically reduce their contribution to air particulates that lead to respiratory illness and death. The EPA states that "Numerous epidemiology studies show an increased mortality rate with elevated levels of ambient particulate matter" (Particulate Matter, 2013).

SimaPro calculates HDPE produces 0.00456 kg PM, while PVC nearly doubles this by expelling 0.00756 kg PM per kg of fiber optic cable produced. Given that any amount of Particulate Matter (PM) in the air supply of humans is detrimental, any reduction is noteworthy.

Using the information provided by the North and South Carolina area construction budget, the provider used roughly 2294km (1425mi) of fiber optic cable last year comprising a weight range between 332,630kg– 649,200kg. Simple arithmetic finds that if this cable was entirely PVC and it been switched to entirely HDPE, this telecom provider would have reduced the total particulate matter linked to respiratory issues for the Carolinas Region by 3.378 Million kg PM and 18.99 Million kg PM per year nationwide on average.

Table 33: Social impact analysis based on respiratory data for North and South Carolina

	kg PM	Fiber Distance (km)	Fiber Weight - Low	Fiber Weight - High	Fiber Weight - Avg	kg PM (Low)	kg PM (High)	kg PM (Avg)
HDPE	0.00456	2294	332,630	649,202	490,916	3.48E+06	6.79E+06	5.14E+06
PET	0.00605	2294	332,630	649,202	490,916	4.62E+06	9.01E+06	6.81E+06
PVC	0.00756	2294	332,630	649,202	490,916	5.77E+06	1.13E+07	8.51E+06

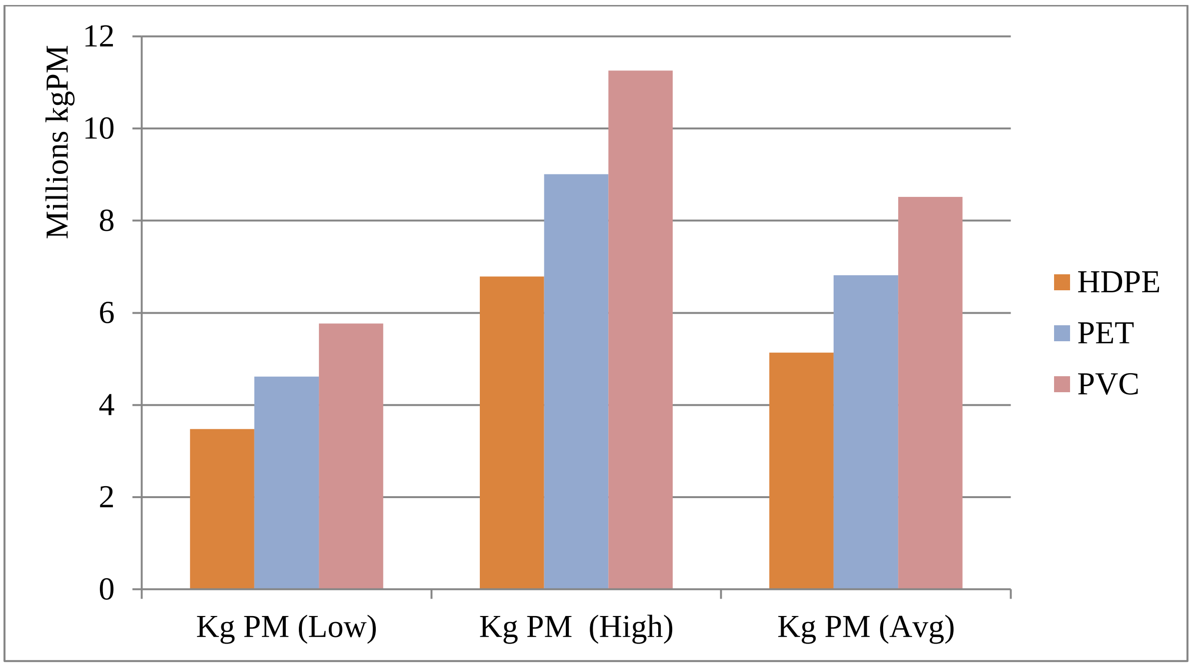


Figure 29: Social impact analysis based on respiratory data for North and South Carolina

CHAPTER 10: SUMMARY AND CONCLUSIONS

The world of telecommunications is, and forever will be, in a state flux; with the introduction of groundbreaking technology occurring daily, major corporations will struggle to keep their networks up to date. Due to this fast, ever changing market, shortcuts are often made in order to earn a quick profit. In doing so, companies must be dubious of their environmental and social impact, ever mindful of the triple bottom line, as our future is important to the longevity of not only the company but society as a whole.

In this study, a sustainable purchasing decision process for fiber optic cable jacketing materials for a major ISP was investigated. We approached the problem in a multi-criteria decision making framework to tradeoff between the economic, environmental and social pillars of sustainability. For the purpose of the sustainable purchasing decision process, metrics related to these three pillars of sustainability were selected and three product alternatives were evaluated. Due to limited data a detailed sensitivity analysis was conducted to investigate the robustness of the decisions. An impact analysis was provided to investigate the bigger potential impact of the findings in this study.

We will next summarize the major findings and conclusions, limitations of this study and potential future research extensions.

10.1: Major Conclusions

Through a great deal of research, this paper created an alternative, repeatable, method for reviewing and analyzing fiber optic cable purchases based on the polymer used in the jacket. It is clear through this research that the emphasis and interest with regards to the environmental and social effects of industry products and processes still remain on an unequal plane in the eyes of purchasing experts.

Based on the cables sourced by the telecommunications provider, further investment should be placed in producing cables comprised of High-Density Polyethylene in order to achieve a more sustainable network that is not only focused on Economic and Social influences, but an Environmental influence as well, one that is truly sustainable.

Based on the research in this study using the initial purchasing decision weighting provided by the ISP procurement specialists, HDPE was proven to be the most environmentally mindful material with a total environmental score of 0.418 compared to the closest competition, PVC, with a total environmental score of 0.302. Furthermore, with regards to the social sustainability testing, HDPE (0.379) again surpassed PVC (0.326) and PET (0.294). Overall HDPE unequivocally demonstrated its potential sustainability once further consideration was given to the social and environmental pillars of sustainability. Clearly the environmental benefits of HD-Polyethylene are substantial with comparisons to other fiber optics jacketing plastic materials currently being used.

10.2: Limitations

Though thorough, this study faced limitations in various areas that are noteworthy. As stated earlier, with regards to the limitations of sustainable data collection, this study was limited in the true mixture of plastic material being utilized by the fiber optic manufacturer due to confidential business information. The exact mixture was deemed proprietary information and therefore limited the data to company defined materials in certain products.

It should also be noted that this study was limited in the number of expert opinions being utilized as well as the number of companies being reviewed. Assumptions were made with regard to the total purchasing process and preferences based on the limited number of survey participants.

Product quality and compliance to standards were taken here as product qualifiers since all products satisfied the work specifications but in reality, while the products meet the specifications, they may have quality and level of compliance differences. More detailed analysis would be possible if the product vendors would provide more detailed information but due to company policies it was not possible to do so in this study.

In order to address the limitations noted here, extensive sensitivity analysis was included in order to expand the potential variations that could have occurred with a much more expansive study.

10.3: Future Research

Future research may include investigation of other cable types since large producers of cabling, whether it be fiber optic, coaxial or twisted pair would benefit from extensive research in alternative materials. This paper was limited in scope in many ways regarding the materials that could be reviewed as well as the exact proprietary mixture of each protective jacket. Due to the inquiries posed by this study, the legal and engineering departments of the ISP provider in this paper has begun questioning large cable producing manufactures about the exact mixture included in all cable manufacturing.

Secondary to further environmental research regarding the proprietary mixture of plastics, an economic question was raised during this research that could spell even greater cost savings for not only manufactures but consumers as well, can the jacketing material be thinned in order to reduce the amount of material used during production? There are already considerable additions to cabling jacketing to provide a stronger yet more flexible cable for use such as Kevlar and pliable metal materials but how much of that can be reduced to still provide the same level of protection.

Although this paper used the specification sheet provided by the telecom provider’s materials engineering department, further engineering research could most certainly revolve around obtaining actual samples of the cabling to conduct materials lab testing to further delineate the strengths and weaknesses of each of these plastics, which can help to analyze the quality of each cable more precisely. Lastly, there lies an opportunity to perform this method again with alternative ISPs and fiber optic cable manufacturers.

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APPENDIX A: PURCHASING DECISION SURVEYS

Listed below are the Initial Purchasing Surveys taken by strategic procurement and purchasing professionals at the telecom provider. These surveys were conducted by taking an AHP Pairwise Comparison of each of the criteria that define sustainability. The surveyors were instructed to rate each of these criteria against each other with regards to their relative importance when making fiber purchasing decisions for a large telecom provider.

		1	2	3	**Geometric Mean**	**Criteria Weights**
		Economic	Environmental	Social		
1	Economic	1	3 1/2	2 1/4	1.99	57.27%
2	Environmental	2/7	1	1/2	0.52	15.05%
3	Social	4/9	2	1	0.96	27.68%
Director, Procurement	Consistency Index Random Index Consistency Ratio	0.00351 0.58 0.0061				
10/17/2014						
NC						

		1	2	3	**Geometric Mean**	**Criteria Weights**
		Economic	Environmental	Social		
1	Economic	1	5	5	2.92	66.13%
2	Environmental	1/5	1	1/9	0.28	6.36%
3	Social	1/5	9	1	1.22	27.51%
Director, Purchasing	Consistency Index Random Index Consistency Ratio	.28042 0.58 0.4835				
10/15/2014						

		1	2	3	**Geometric Mean**	**Criteria Weights**
		Economic	Environmental	Social		
1	Economic	1	5	4	2.71	67.38%
2	Environmental	1/5	1	1/3	0.41	10.07%
3	Social	1/4	3	1	0.91	22.55%
Dir., Strategic Procurement	Consistency Index	.04288				
	Random Index	0.58				
	Consistency Ratio	0.0739				
10/14/2014						
NC						

APPENDIX B: ENVIRONMETNAL TRACI IMPACT CRITERIA SURVEYS

ENVIRONMENTAL		1	2	3	4	5	6	Geometric Mean	Criteria Weights
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1	1/9	1/3	1/7	1/5	1/8	0.23	2.53%
2	Global Warming	9	1	7	3	5	2	3.52	39.47%
3	Smog	3	1/7	1	1/5	1/3	1/6	0.41	4.60%
4	Acidification	7	1/3	5	1	2	1/2	1.51	16.90%
5	Eutrophication	5	1/5	3	1/2	1	1/4	0.85	9.53%
6	Eco-toxicity	8	1/2	6	2	4	1	2.40	26.96%
Name:	Dongwook Kim							8.91	100.00%
Title:	Ph.D. Student						Consistency Index	0.046	
Date/Time:	4/15/2014						Random Index	1.240	From the Table
Place:	UNCC						Consistency Ratio	0.037	

ENVIRONMENTAL

		1	2	3	4	5	6	Geometric Mean	Criteria Weights
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1	1/9	1/3	1/7	1/5	1/8	0.23	2.53%
2	Global Warming	9	1	7	3	5	2	3.52	39.47%
3	Smog	3	1/7	1	1/5	1/3	1/6	0.41	4.60%
4	Acidification	7	1/3	5	1	2	1/2	1.51	16.90%
5	Eutrophication	5	1/5	3	1/2	1	1/4	0.85	9.53%
6	Eco-toxicity	8	1/2	6	2	4	1	2.40	26.96%
								8.91	100.00%

Name:	Dongwook Kim
Title:	Ph.D. Student
Date/Time:	4/15/2014
Place:	UNCC

Consistency Index	0.046	
Random Index	1.240	From the Table
Consistency Ratio	0.037	

ENVIRONMENTAL

		1	2	3	4	5	6	Geometric Mean	Criteria Weights
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1	1	5	3	5	3	2.47	32.07%
2	Global Warming	1	1	5	3	5	3	2.47	32.07%
3	Smog	1/5	1/5	1	1	3	3	0.84	10.97%
4	Acidification	1/3	1/3	1	1	3	3	1.00	13.00%
5	Eutrophication	1/5	1/5	1/3	1/3	1	1/3	0.34	4.39%
6	Eco-toxicity	1/3	1/3	1/3	1/3	3	1	0.58	7.51%
								7.69	100.00%

Name:	Shubhashini Oza
Title:	Research Associate, UNC Charlotte
Date/Time:	3/13/2015
Place:	Charlotte

Consistency Index	0.082	
Random Index	1.240	From the Table
Consistency Ratio	0.066	

ENVIRONMENTAL

		1	2	3	4	5	6	Geometric Mean	Criteria Weights
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1	2/9	1 1/4	3	4/9	1/3	0.71	
2	Global Warming	4 1/2	1	4 1/2	9	3	1 4/5	3.15	8.79%
3	Smog	4/5	2/9	1	1 1/2	3/5	1/4	0.58	39.28%
4	Acidification	1/3	1/9	2/3	1	2/3	1/6	0.37	7.28%
5	Eutrophication	2 1/4	1/3	1 2/3	1 1/2	1	1/4	0.88	4.66%
6	Eco-toxicity	3	5/9	4	6	4	1	2.33	10.98%
Name:	Helene Hilger							8.03	29.02%
Title:	Emerita Civil Engineering Faculty Member						**Consistency Index**	0.038	100.00%
Date/Time:	3/13/2015						**Random Index**	1.240	
Place:	Charlotte, NC						**Consistency Ratio**	0.030	From the Table

ENVIRONMENTAL

		1	2	3	4	5	6	Geometric Mean	Criteria Weights
		Ozone Depletion	Global Warming	Smog	Acidification	Eutrophication	Eco-toxicity		
1	Ozone Depletion	1	1/5	1	1/5	1	1	0.58	7.14%
2	Global Warming	5	1	5	1	5	5	2.92	35.71%
3	Smog	1	1/5	1	1/5	1	1	0.58	7.14%
4	Acidification	5	1	5	1	5	5	2.92	35.71%
5	Eutrophication	1	1/5	1	1/5	1	1	0.58	7.14%
6	Eco-toxicity	1	1/5	1	1/5	1	1	0.58	7.14%
Name:	David J. Kinnear							8.19	100.00%
Title:	Process Engineer						**Consistency Index**	0.000	
Date/Time:	3/12/2015						**Random Index**	1.240	From the Table
Place:	HDR Engineering						**Consistency Ratio**	0.000	

APPENDIX C: SOCIAL TRACI IMPACT CRITERIA SURVEYS

SOCIAL		1	2	3	Geometric Mean	Criteria Weights
		Carcinogenic	Non Carcinogenics	Respiratory Effects		
1	Carcinogenic	1	2	2	1.59	50.00%
2	Non Carcinogenics	1/2	1	1	0.79	25.00%
3	Respiratory Effects	1/2	1	1	0.79	25.00%
Name:	Dongwook Kim				3.17	100%
Title:	Ph.D. Student			**Consistency Index**	0.00000	
Date/Time:	4/15/2014			**Random Index**	0.58	From the Table
Place:	UNCC			**Consistency Ratio**	0.0000	

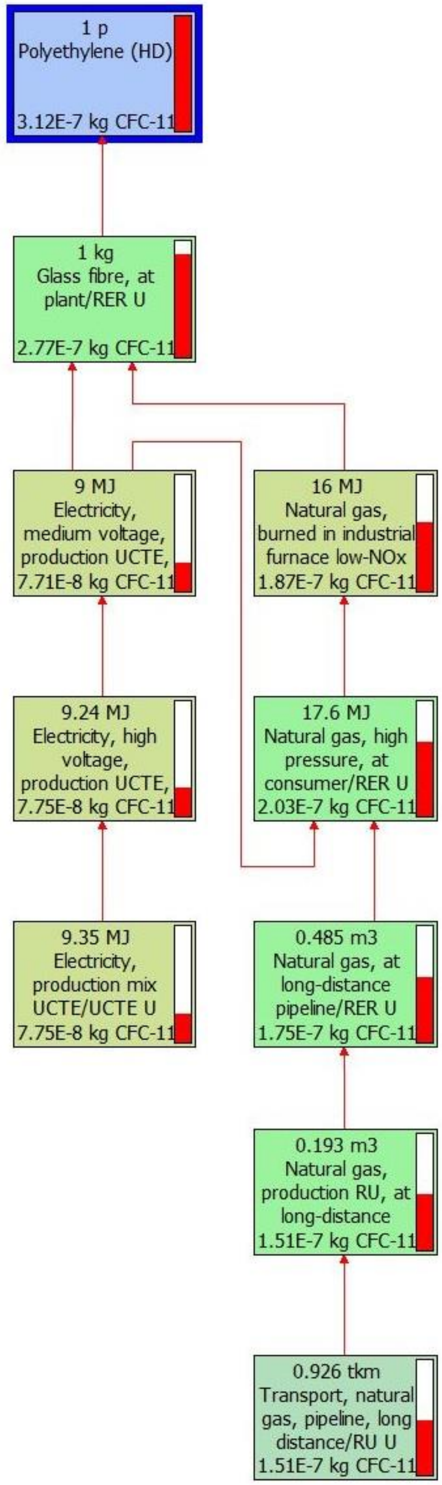
SOCIAL		1	2	3	Geometric Mean	Criteria Weights
		Carcinogenic	Non Carcinogenics	Respiratory Effects		
1	Carcinogenic	1	5	1	1.71	48.06%
2	Non Carcinogenics	1/5	1	1/3	0.41	11.40%
3	Respiratory Effects	1	3	1	1.44	40.54%
Name:	Shubhashini Oza				3.56	100%
Title:	Research Associate, UNC Charlotte			**Consistency Index**	0.01453	
Date/Time:	3/13/2015			**Random Index**	0.58	From the Table
Place:	Charlotte			**Consistency Ratio**	0.0251	

SOCIAL		1	2	3	Geometric Mean	Criteria Weights
		Carcinogenic	Non Carcinogenics	Respiratory Effects		
1	Carcinogenic	1	3	1 1/2	1.65	50.69%
2	Non Carcinogenics	1/3	1	2/3	0.61	18.60%
3	Respiratory Effects	2/3	1 1/2	1	1.00	30.71%
Name:	Helene Hilger				3.26	100%
Title:	Emerita Civil Engineering Faculty Member			**Consistency Index**	0.00460	
Date/Time:	3/13/2015			**Random Index**	0.58	From the Table
Place:	Charlotte, NC			**Consistency Ratio**	0.0079	

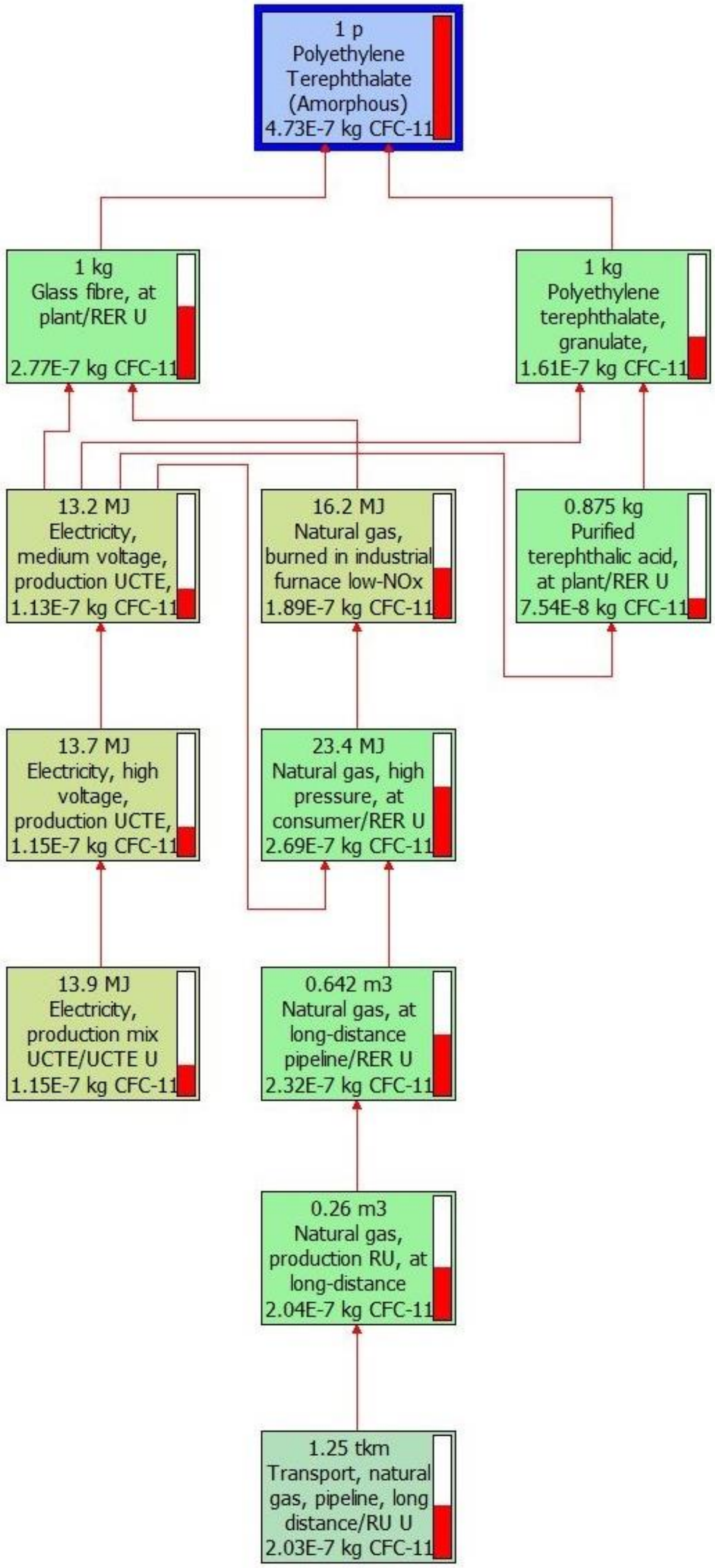
SOCIAL		1	2	3	**Geometric Mean**	**Criteria Weights**
		Carcinogenic	Non Carcinogenics	Respiratory Effects		
1	Carcinogenic	1	5	3	2.47	64.83%
2	Non Carcinogenics	1/5	1	1/2	0.46	12.20%
3	Respiratory Effects	1/3	2	1	0.87	22.97%
Name:	David J. Kinnear				3.80	100%
Title:	Process Engineer			**Consistency Index**	0.00185	
Date/Time:	3/12/2015			**Random Index**	0.58	From the Table
Place:	HDR Engineering			**Consistency Ratio**	0.0032	

APPENDIX D: SIMAPRO SOFTWARE SIMULATIONS

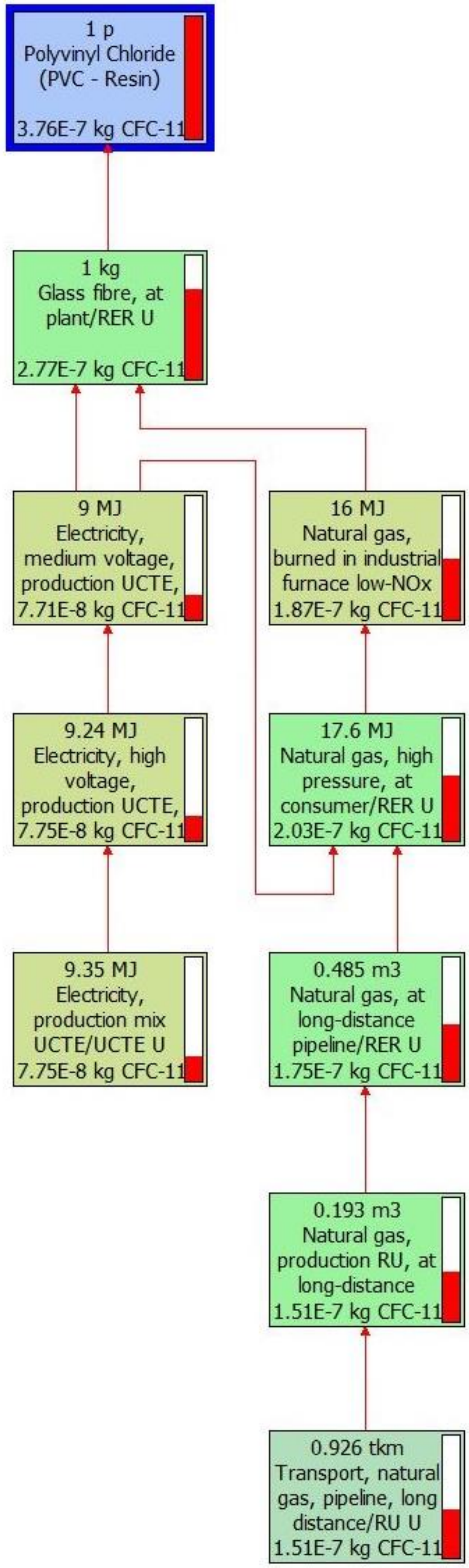
The following diagrams are the Network Trees produced in SimaPro 8 Software used in this research. Each diagram not only shows each piece of raw material but the process that comprised the production of each fiber optic cable as well. For example, the diagram depicting the LCA of High-Density Polyethylene shows the entire production line and all energy and material that goes in to its manufacturing. As you can see, each of these product trees even includes the transport and consumption of natural gas to produce the electricity necessary for the extrusion of the cable. This is a high level view and does not include all factors of the production line but merely the most detrimental and energy-consuming steps. The SimaPro software allows the user to see the entire list of events if they require, however, due to the scope of this study and the size of the chart, this was limited in the appendix to the major contributors.



High-Density Polyethylene



Polyethylene Terephthalate



Polyvinyl Chloride

APPENDIX E: RANDOM INDEX TABLE

Table for Random Index	
n	RIn
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59