CO_2 PRICE IMPACT ON DELL'S SUPPLY CHAIN: A FRAMEWORK FOR CARBON FOOTPRINT ECONOMIC ANALYSIS

By

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Submitted to the Engineering Systems Division and MIT Sloan School of Management in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

The principal scope of this project is to design, analyze and report a case study of how to effectively account for the highly likely scenario of a CO_2 price policy (cap-and-trade or tax) with regard to Dell's product and supply chain. Dell will use the cost implications of total carbon footprint for the supply chain in a strategic design of manufacturing and fulfillment networks. A carbon footprint Life Cycle Assessment (LCA) will be performed on Dell's 15-inch notebook supply chain.

A detailed analysis of the current local and global climate change policy options is discussed. Furthermore, case study examples for the two main policy options, cap-and-trade and tax, are presented and analyzed.

The target product for this study is a notebook manufactured in Asia and delivered to the United States. Results for the notebook show that the largest part of the CO_2 footprint resides in the use phase, the suppliers' phase, and the finish goods transportation phase, with a 76.5, 11.9, and 9.7 percent, respectively. The most likely cost range for the time frame between 2012 to 2020 (phase I) is \$0.04 to \$0.06 per notebook. In the case of a policy implementation with zero percent of free allowance and \$15.00/CO_2-ton, the additional cost per notebook may range between \$1.06 to \$1.77.

We conduct an analysis to determine what carbon price would make manufacturing in the U.S. competitive with manufacturing in China. We find that the average breakeven CO_2 price is \$103/CO_2-ton.

Keywords: *notebook computer, Life Cycle Assessment, LCA, sensitivity analysis, supply chain, climate change policy, energy policy, carbon dioxide*

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Biographical Note:

Ely Colón was born in Bayamón, Puerto Rico and has lived in various parts of Puerto Rico and the United States including Massachusetts, Texas and Wisconsin. Ely attended University of Puerto Rico-Mayagüez and received a BS in Mechanical Engineering. While at UPRM-Mayagüez, Ely was an intern at Johnson & Johnson Co. where he designed and developed a machine for a specific device cleaning process. Ely started his professional career with General Electric within the elite corporate Operations Management Leadership Program (OMLP). His experiences included work in many different industries, including Power Electronics, Consumer Electronics, Medical Devices, and High Tech. Prior to coming to the Leaders for Global Operations program at MIT, Ely worked for GE as Transportation and Logistics Manager. While at GE, Ely earned his 6-sigma Green Belt and APICS – CPIM certifications.

Ely enjoy playing golf, tennis, soccer, tenor saxophone, traveling, reading, and water rafting. He lives with his wife in Cambridge, MA.

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1. INTRODUCTION

This chapter discusses the major motivations behind the research and provides a brief outline of the thesis structure.

1.1 Motivation for Thesis

Several "green" bills have been proposed for the United States and in June 2009 the Waxman-Markey bill was passed by the House (Markey, 2009). Restrictions, tariffs, and/or fees in the Waxman-Markey bill may have significant cost impact on supply chain operations. The Senate version of the bill, Kerry-Boxer (or an updated version), will be brought to the Senate floor for debate in April 2010 (Kerry, 2009). A CO_2 cap-and-trade legislation is already in place in the E.U. since 2005 as part of the Kyoto Protocol agreement. A follow up to Kyoto Protocol took place last December 2009 at Copenhagen, Denmark. Many companies and industries will be affected by these policies and protocols directly or indirectly.

1.2 Organization of Thesis

This thesis is organized into six chapters as outlined below:

Chapter 1 – Introduction: Describes the major motivations and goals of the thesis. A description of the company, including past and present operation models and financial transitions is also provided.

Chapter 2 – Global Warming and CO_2 Footprint: Provides context and relevant background information regarding global warming and CO_2 footprint. It also discusses international agreements that target greenhouse gases.

Chapter 3 – CO_2 Price Policy: Provides context on the policy objectives, the different policy alternatives and two case studies examining the two main policy structures in practice nowadays; CO_2 cap-and-trade and CO_2 tax. The chapter explains the price dynamics and the timeline for every major upcoming CO_2 policy event and its main target.

Chapter 4 – Dell's Supply Chain CO_2 Footprint Approach: Analyzes and provides a framework to quantify Dell's CO_2 footprint through a Life Cycle Assessment (LCA). It also provides background information for industry accepted approaches and frameworks.

Chapter 5 – Methodology: Offer the assumptions and the data we use to make the analysis and calculations.

Chapter 6 – Results and Financial Impact: Offers the allocated fraction of CO_2 per unit-supply chain scenario, and a low, medium, high CO_2 permit price setting to calculate the additional CO_2 price per notebook unit. A literature comparison is done for different computer components and computer per se. A scenario analysis is performed in order to study the parameters needed to move notebook assembly back to the United States. A set of recommendations will be provided for supply chain network decisions.

Chapter 7 – Conclusions and Outlook.

1.3 Company Overview

Founded in 1984, Dell has emerged as the world's leading direct-sale computer vendor. The company's eponymous founder, Michael Dell, started the company in his dorm-room at the University of Texas and through an innovative direct-sales and build-to-order manufacturing strategy, achieved the number one position in global PC market share in 2001. Headquartered in Round Rock, Texas, Dell today has annual sales of \$61.1 billion USD (FY 2009), net income of

$2.5 billion (FY 2009) and employs 78,900 people worldwide.[1] Although it began as a PC company, Dell now offers a variety of products and services including servers, storage devices, workstations, mobility products, IT services, and software and peripheral products such as printers, monitors, and projectors. These products are sold to two main customer segments: relationship buyers and transactional buyers. Relationship buyers are comprised of large corporations, government and educational institutions that generally make repeat purchases from Dell and establish a continuing relationship with Dell. Transactional buyers are consumers or small businesses who generally treat each buying decision as a separate transaction (Ngai, 2007). Historically, relationship buyers have accounted for an overwhelming 75+ percent of Dell sales.

Recently, market trends have led Dell to refocus efforts on increasing sales to transactional buyers. In addition to establishing a Small and Medium Business Segment, Dell has created a Global Consumer Division to spur sales to consumers. Historically, consumer sales have accounted for less than 15% of Dell's total sales. Dell has made the decision to re-enter the retail space for a second time since 1990 in hopes of generating significant new business among consumers, many of whom want to physically touch and feel a unit before they buy. This new channel strategy has introduced a slew of challenges to Dell's supply chain, which will be discussed further in this chapter and which have been part of the motivation for this thesis.

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[1] Hoovers.com

1.3.1 Company Growth Transition

The following section examines Dell from a life cycle perspective. The purpose is to understand the main reasons for the company transitioning from the Old Supply Chain (OSC) strategy to the New Supply Chain (NSC) strategy, explained further in this chapter.

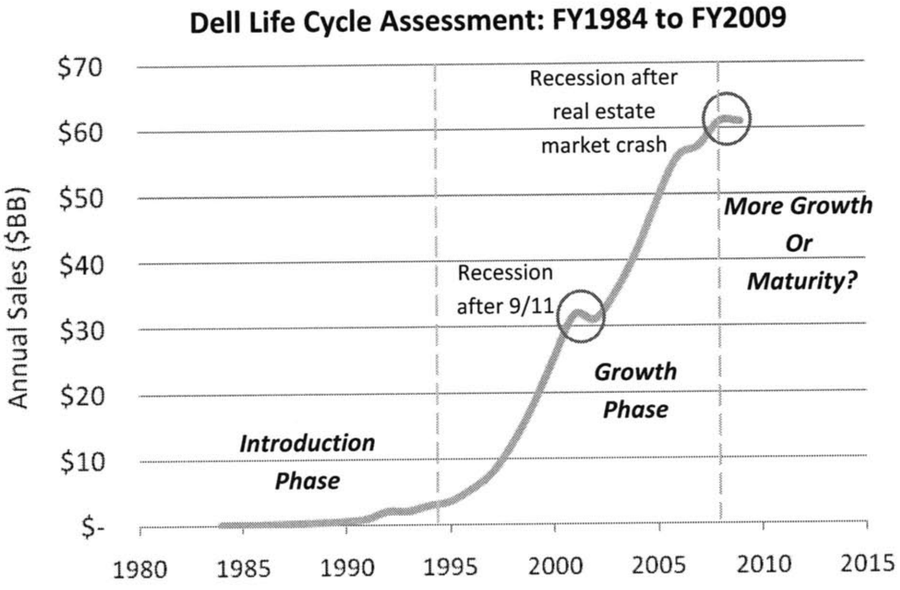

Figure 1-1: Dell's Life Cycle: FY1984 to FY2009.

Figure 1-1 shows annual sales from FY1984 to FY2009 with an average compound annual growth rate of 40 percent. After decades of this hyper-growth, Dell is entering a new phase in their life cycle. The company recognizes the need to diversify its portfolio of products and services, and hence, to develop new strategies and business models. As Figure 1-1 shows, there is not a definitive trend of what will come next after FY2009. The second red circle shows the current recession after the real estate market crash a year ago. But a similar economic recession occurred after 9/11 events, and still growth was averaging a 10 percent annual rate. From FY2008 to FY2009 growth was zero percent. It is pretty certain that the previous hyper-growth experienced by the company is no longer existent. New strategies and business model might be necessary in order to maintain the company's leadership and growth for the years to come.

1.4 Supply Chain Strategy Overview

The upstream supply chain of many companies and industries (consumer goods, high-tech, and other manufactures) accounts in many cases for 40 to 60 percent of the CO_2 footprint (Ungerman, 2008). This takes into account raw materials, transport, and packaging to the energy consumed in manufacturing processes. Dell was founded in 1984 on a simple concept: "by selling computer systems directly to customers, we could best understand their needs and efficiently provide the most effective computing solutions to meet those needs".[1] The now famous *Direct Model* was born and quickly developed into a source of great competitive advantage to Dell. Dell allowed its customers to customize a product over the internet and successfully manufactured and delivered these computers to customers with a lead time of 5 days (Spera, 2003). The Direct Model is the most efficient path to the customer, thereby forming the relationships required to truly understand customer needs.[2] There are several advantages to this business model, including access to sales information directly from the customer, ability to respond more quickly to demand, retain lower levels of inventory and maintain a negative cash conversion cycle. Because of Dell's intensive supply chain business model (mainly transportation, and assembly) it is very important to understand its network in order to better estimate its CO_2 footprint. Below, Figure 1-2 illustrates the traditional PC supply chain with Distributors and Retailers acting as the interface between the PC Manufacturer and the Customer.

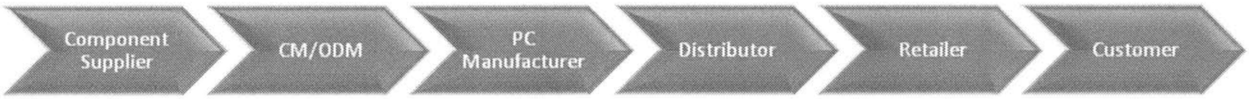

Figure 1-2: Traditional PC supply chain model

[1,2] Dell Corporate Website

1.4.1 Old Supply Chain - Dell

The Old Supply Chain (OSC) of Dell is mainly characterized by the following: a) located in high cost countries, b) based on regional processes, c) fixed cost structure, and d) one size fits all market segments. Figure 1-3 shows a schematic representation of the current model, OSC. It is a two-dimensional matrix comparing flexibility vs. time to customer and allocating Dell's two main segments into the matrix.

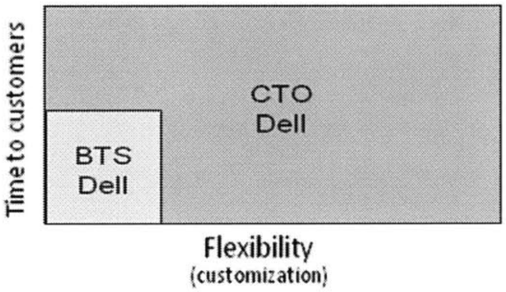

Figure 1-3: OSC, Time to customers vs. Flexibility matrix model.[3]

There were two main components to Dell's historical success in implementing the Direct Model: Build-to-order manufacturing (BTO) and Just-In-Time (JIT) inventory. Build-to-order manufacturing bypassed the retail channel and eliminated a potentially powerful and costly part of the value chain. Dell could schedule customized builds when customer orders were placed, which permitted Dell to employ the Just-In-Time (JIT) inventory strategy to reduce overall inventory within its supply chain and pass on savings to the customers. The figure below illustrates Dell's Build-to-Order supply chain.

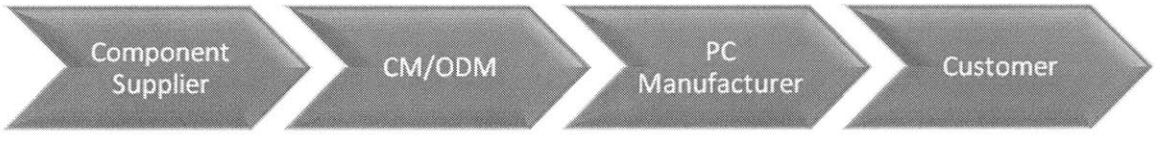

Figure 1-4: Dell's Build-to-Order Supply Chain

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[3] CTO = Costumed To Order, BTS = Build To Stock

In addition, Dell used a strategy of assembling the finished product close to the ultimate customer destination, to reduce lead-times and fulfillment costs. Dell has a manufacturing presence around the world to serve these customers. Dell-owned factories in the US, Brazil, Ireland, Poland, Malaysia, China and India receive orders from each region and deliver customized finished products to customers. These products include servers, storage devices, workstations, desktop computers and mobility products. Certain products are manufactured by Contract Manufacturers (CM) or Original Design Manufacturers (ODM) and are received in Dell's Distribution Centers (DC) around the world. These include non-customizable products such as printers, monitors and other peripherals.

1.4.2 New Supply Chain - Dell

The New Supply Chain (NSC) is mainly characterized by the following: a) low cost countries, b) global standards, c) variable cost structure, and d) segmented supply chain menu. Figure 1-5 shows a schematic representation of the future/in-transition model, NSC. It is a two-dimensional matrix comparing flexibility vs. time to customer and allocating Dell's two main segments into the matrix. The left side of Figure 1-5 shows the relationship of flexibility and time to customers for fixed configuration, the right side is for configure to order.

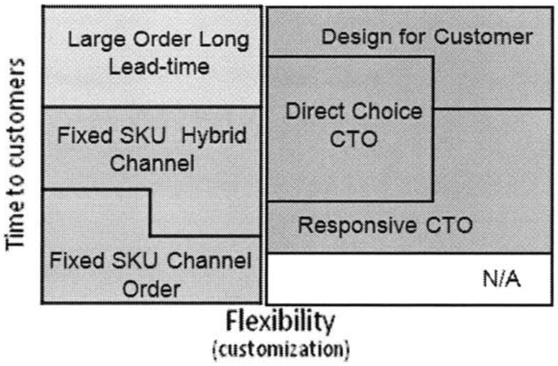

Figure 1-5: NSC, Time to customers vs. Flexibility matrix model

The following Table 1-1 shows the net changes from OSC to NSC in terms of Dell's global footprint:

Table 1-1: Net physical footprint changes after NSC complete implementation

Sites	Net Change to NSC
Dell Manufacturing Plants	-58%
Fulfillment Centers	+16%
Original Design Manufacturers (ODM)	+10X

One of the main conclusions out of Table 1-1 is the new Dell's focus of going from a high fixed cost structure to a high variable cost structure, entailing increased usage of ODM and FCs.

1.5 Chapter Summary

Over its life, Dell has experienced an average compound annual growth rate of 40 percent. During the last seven years, the average growth has declined to 10 percent. Even with the success that Dell obtained from its innovative and efficient business model, Build-to-Order, for the last 25 years, the company is entering into a new life cycle phase and is looking to increase its portfolio of market segments and services. Right now Dell is in a transition from OSC, its original business model, to NSC a more diversified and different business model. Table 1-2 summarizes the main difference between OSC and NSC.

Table 1-2: Summary of main differences between OSC and NSC

Supply Chain Model	Old	New
Locations	High Cost Country	Low Cost Country
Processes	Regional Processes	Global Standards
Cost Structure	Fixed Cost Structure	Variable Cost Structure
Flexibility	One Size fits all	Segmented Supply Chain Menu

Dell is a global company with presence in almost every continent. Dell's global footprint is transitioning from a high-cost-country, high fixed cost to a low-cost-country and variable cost structure, as shown in Table 1-2. The principal objective of the future chapters will be to investigate the potential associated costs for Dell from a CO_2 global policy perspective. In order to understand these potential impacts, it is very important to understand Dell's supply chain and business model. That was the purpose of this chapter.

2. GLOBAL WARMING AND CO_2 FOOTPRINT REVIEW

Since the early 1990's, scientists, global organizations, and leaders have been tracking the average increase in worldwide temperature and its correlation with Greenhouse Gases (GHG), especially Carbon Dioxide (CO_2). Dell has publicly disclosed their commitment with environmental sustainability and its leadership on this topic. A detail explanation of global warming, footprints and Dell's environmental commitment is discussed in this chapter. Additionally, the chapter ends with a discussion and explanation of the main protocols placed worldwide to tackle the global warming issue.

2.1 Dell's Environmental Commitment

"At Dell, we're committed to becoming the greenest technology company on the planet" – Michael Dell (Dell, 2008). Dell recognizes that climate change is real and must be mitigated, and they support efforts to reduce global emissions to levels guided by the evolving science. Dell also supports the various efforts underway to develop a scientific and policy consensus on target reduction levels, including the work of the Intergovernmental Panel on Climate Change (IPCC), whose 4th assessment report indicated that global reductions of 50-85% by 2050 from 2000 levels are necessary to achieve recommended greenhouse gas stabilization levels. While the most recent IPCC conclusions are not the last word, they contribute to the framework for building the broad public policy consensus that must emerge. The solution to the global climate crisis requires action from both developed and developing countries. Dell commits to contribute to this policy debate internationally.

2.2 What is Global Warming?

Global warming is an increase in the average temperature of the earth's atmosphere, especially a sustained increase that causes climatic changes.[4] CO_2 and other air pollutants are collecting in the atmosphere like a thickening blanket, trapping the sun's heat and causing the planet to warm up. Although local temperatures fluctuate naturally, over the past 50 years the average global temperature has increased at the fastest rate in recorded history. Experts think the trend is accelerating: the 10 hottest years on record have all occurred since 1990. Scientists say that unless we curb global warming emissions, average U.S. temperatures could be three to nine degrees higher by the end of the century (Natural Resources Defense Council, 2009). Section 2.4 will discuss in more detail the most popular agreement taken so far between countries and international agencies to abate GHG emissions and to that end, global warming.

2.3 What is Carbon or CO_2 Footprint?

A carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. It relates to the amount of greenhouse gases produced in our day-to-day lives through burning fossil fuels for electricity, heating, transportation, etc. The carbon footprint is a measurement of all greenhouse gases we individually produce (Carbon Footprint, 2009) and has units of tons (or kg) of carbon dioxide equivalent (CO_2-e).[5]

A carbon footprint is made up of the sum of two parts, the primary footprint and the secondary footprint:

1. The primary footprint is a measure of our direct emissions of CO_2 from the burning of fossil fuels including domestic energy consumption and transportation (e.g. car and plane). We have direct control of these.

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[4] from Princeton University web-based dictionary: wordnetweb.princeton.edu/perl/webwn

[5] All units of ton refers to metric ton (1 metric ton = 1000 kg)

2. The secondary footprint is a measure of the indirect CO_2 emissions from the whole lifecycle of products we use - those associated with their manufacture and eventual breakdown.

2.3.1 What is Supply Chain CO_2 Footprint?

Now that we have a better understanding of Global Warming, CO_2 footprint and Climate change, let's discuss its implications on the supply chain of companies. Supply Chain CO_2 footprint refers to the amount of CO_2 emission that is released to the environment throughout the end-to-end process of creating, selling and disposing a product or service. Supply chain management (SCM) is the combination of art and science that goes into improving the way a company finds the raw components it needs to make a product or service and deliver it to customers. The following are five basic components of SCM: (1) plan, (2) source, (3) make, (4) deliver, and (5) return (SCC, 2006).

Managing the carbon footprint of products across the supply chain is the next step for business to take in the effort to reduce carbon emissions and mitigate climate change. There are several issues driving business to take action, including:

- Increases in direct energy costs and the energy costs of suppliers.
- Existing and planned legislation which penalizes high energy consumption and rewards emissions reductions.
- Changing consumer attitudes to climate change, presenting forward-thinking companies with an opportunity to develop and market low-carbon products.

As we move to a more carbon-constrained world, business will ultimately have to meet customer needs in a way that generates fewer carbon emissions. Business energy efficiency and low-carbon energy supply have played, and will continue to play, an important role but more fundamental solutions are also needed. Managing the carbon footprint of products across the supply chain is just such a solution. Managing the carbon footprint of a product means minimizing the carbon emissions required to deliver that product to the end consumer. Additionally, a direct relationship between reducing emissions and reducing cost has been noted, as emissions are a lagging indicator of waste (Aberdeen Group, 2008).

2.4 Global Climate Change Agreements

Over a decade ago, most countries joined an international treaty -- the United Nations Framework Convention on Climate Change (UNFCCC) -- to begin to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. More recently, a number of nations approved an addition to the treaty: the Kyoto Protocol 1997, which has more powerful (and legally binding) measures. The UNFCCC secretariat supports all institutions involved in the climate change process, particularly the Conference of the Parties (COP), the subsidiary bodies and their Bureau (UNFCC, 1997). The following sections discuss in more detail the Kyoto protocol and its follow-up, the Copenhagen Climate Summit 2009.

2.4.1 The Kyoto Protocol

The Kyoto Protocol is an international agreement linked to the UNFCCC. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing GHG emissions. The most notable non-member of the Protocol is the United States, which is a signatory of UNFCCC and was responsible for 36.1% of the 1990 emission levels.

The major distinction between the Protocol and the Convention is that while the Convention encouraged industrialized countries to stabilize GHG emissions, the Protocol commits them to do so. Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. 184 Parties of the Convention have ratified its Protocol to date. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh in 2001, and are called the "Marrakesh Accords." The Kyoto mechanisms are the followings:

1. Emission trading:[6]

Greenhouse gas emissions – a new commodity. Parties with commitments under the Kyoto Protocol (Annex B Parties) have accepted targets for limiting or reducing emissions. These targets are expressed as levels of allowed emissions, or "assigned amounts," over the 2008-2012 commitment period. The allowed emissions are divided into "assigned amount units" (AAUs). Emissions trading, as set out in Article 17 of the Kyoto Protocol, allows countries that have emission units to spare - emissions permitted them but not "used" - to sell this excess capacity to countries that are over their targets. Thus, a new commodity was created in the form of emission reductions or removals. Since CO_2 is the principal greenhouse gas, people speak simply of trading in carbon. Carbon is now tracked and traded like any other commodity. This is known as the "carbon market."

2. Clean development mechanism (CDM):[7]

The Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one ton of CO_2, which can be counted towards meeting Kyoto targets. The mechanism is seen by many as a trailblazer. It is the first global, environmental investment and credit scheme of

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[6] http://unfccc.int/kyoto_protocol/mechanisms/emissions_trading/items/2731.php

[7] http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

its kind, providing a standardized emission offset instrument, CERs. A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction or limitation targets.

3. Joint Implementation (JI):[8]

The mechanism known as "joint implementation," defined in Article 6 of the Kyoto Protocol, allows a country with an emission reduction or limitation commitment under the Kyoto Protocol (Annex B Party) to earn emission reduction units (ERUs) from an emission-reduction or emission removal project in another Annex B Party, each equivalent to one ton of CO_2, which can be counted towards meeting its Kyoto target. Joint implementation offers Parties a flexible and cost-efficient means of fulfilling a part of their Kyoto commitments, while the host Party benefits from foreign investment and technology transfer.

2.4.2 Copenhagen Climate Summit

In 2012 the Kyoto Protocol to prevent climate changes and global warming runs out. To keep the process on the line there is an urgent need for a new climate protocol. At the conference in Copenhagen 2009 (December), the parties of the UNFCCC met for the last time on government level before the climate agreement needs to be renewed. Therefore the Climate Conference in Copenhagen is essential for the world's climate and the Danish government and UNFCCC is putting hard effort in making the meeting in Copenhagen a success ending up with a Copenhagen Protocol to prevent global warming and climate changes. The main effort has been to incorporate the United States and reach agreement between U.S. and China among other things. Neither of these two countries wants to commit to a binding agreement without a first commitment from the other. International negotiations in Copenhagen last month failed

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[8] http://unfccc.int/kyoto_protocol/mechanisms/joint_implementation/items/1674.php

to reach a binding legal agreement in part because the US, the world's largest historical emitter of greenhouse gas emissions, has yet to adopt domestic reduction targets. The Senate's Kerry-Boxer bill: Clean Energy Jobs and American Power Act, will be brought to the Senate floor for a debate in April 2010. UN negotiators have high hopes the US will have committed to domestic targets by the time they meet again in Mexico City next November 2010.

2.5 Chapter Summary

Since the early 1990's, scientists, global organizations, and leaders have been tracking the average increase in worldwide temperature and it's correlation with Greenhouse Gases (GHG). Based on the established correlation between GHGs and Global Warming, the international community decided to design a legal binding document, The Kyoto Protocol, in 1997 to tackle the GHG emissions worldwide. The implementation phase is from 2008 to 2012. A follow-up to that protocol is the Copenhagen Climate Summit on December 2009. The big missing country in the reduction emission binding document from The Kyoto Protocol is the United States. International negotiations in Copenhagen last month failed to reach a binding legal agreement in part because the US, the world's largest historical emitter of greenhouse gas emissions, has yet to adopt domestic reduction targets.

Managing the carbon footprint of products across the supply chain is the next step for business to take in the effort to reduce carbon emissions and mitigate climate change. As we move to a more carbon-constrained world, business will ultimately have to meet customer needs in a way that generates fewer carbon emissions. Dell has publicly disclosed their commitment with environmental sustainability and its leadership on this topic and is actually taking steps toward this goal of emissions reduction and environmental sustainability while growing their businesses. The study presented here is one of the progressive initiatives that Dell is undertaking to understand their supply chain for a specific product and recognize the main components affecting their product CO_2 footprint. This will give the basis for further studies and analysis for a broader portfolio of products and operations performed by Dell.

3. CO_2 PRICE POLICY

The last chapter explained global warming and some of the most important global treaties that are in order to abate the excess of GHGs in our atmosphere. Now, in this Chapter 3, we explain in more detail some economic policies that have been proposed in order to tackle this international issue. We will explain their dynamics and will discuss some case studies in which countries have implemented one or more policies.

3.1 CO_2 Cap-and-Trade Policy

CO_2 (or Carbon) Cap-and-Trade is a market based mechanism system that identifies emitting entities, sets a cap on total emissions, distributes emission allowances to covered entities[9] that in total equal the cap, requires entities to turn in allowances equal to their emissions in each period (e.g., year), and allows trade so that a market for pricing and trading emission allowances is established (S. Paltsev, 2007).

What does "cap-and-trade" mean?

A "cap" is a legal limit on the quantity of greenhouse gases an economy can emit each year. Over time, the legal limit diminishes—the cap gets tighter—until we've hit our targets and launched a clean-energy economy. The cap acts as a solid backstop behind all other climate policies (Durning, 2009). Energy efficiency standards for vehicles and appliances, smart-growth plans, building codes, transit investments, tax credits for renewable energy, public investment in energy research and development, utility regulatory reforms—all manner of public actions can move an economy, e.g., the US, toward the climate goals.

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[9] Covered entities = industry specific companies that are required to participate under the CO_2 price policy. This is based on their annual CO_2 emissions

"Trade" means that, by law, companies may swap among themselves the permission to emit GHG. In other words, there is a market for pollution "permits" or "allowances". The point of such a trading system is to put a price on pollution that will travel throughout the economy, motivating businesses and consumers to find ways to trim greenhouse gases.

How does "cap-and-trade" work?

Here are the basic steps to operating a cap-and-trade system (Durning, 2009):

1. *Tally greenhouse-gas emissions.* For example, track and record fossil fuel quantities/volumes at the points where they enter the economy: the pipeline, mines or oil tanker. Once we know the volume of each fuel, we can then calculate the amount of future CO_2 emissions that will occur at the combustion point of all that imported fuel. The Congressional Budget Office estimates the number of US companies at such entry points as 7,400.

2. *Set a cap.* Decide how much carbon pollution to allow in the program's first year and require permits for emissions: one permit per ton of CO_2 or CO_2-e. The number of permits will match the cap to ensure we hit our goals. (A cap does not limit emissions from individual citizens; no paperwork for families or small businesses is required. Instead, it affects wholesalers or suppliers of fossil fuels and similar big "upstream" businesses. Price signals travel downstream through the economy to other businesses and to consumers.)

3. *Distribute permits.* Permits can be valid for a single year, or for a multi-year period. One method for distributing them is auctioning; another is to give them away free on the basis of past emissions ("grandfathering"), past energy sales, or some other criterion. Permit holders can buy and sell allowances among themselves. That is the "trade" part.

4. *Enforce the cap.* Affected businesses (for example, those that bring fossil fuels into the economy) will file periodic reports verifying that they hold enough permits to cover their emissions. Authorities will audit reports to deter misrepresentation. They will curb speculation and gaming by overseeing the permit market.

5. *Step it down.* Each year, distribute fewer emissions permits, on a predictable, published schedule that takes us to our targets. The gradual nature of this transition maximizes choice and flexibility in a way that narrowly targeted climate policies cannot match.

Within this general description, cap and trade can vary, depending on how a specific system is designed. Key design choices make a world of difference. The congressional bills for a cap-and-trade policy have established a minimum of 10,000 tons of CO_2/year per company in order to be part of this policy. Assuming this criterion applies worldwide then nine percent of Dell's facilities, worldwide (distribution centers, office buildings, warehouses, manufacturing sites) would be required to participate under this cap-and-trade policy. If the policy is just placed in the U.S., six percent of Dell's facilities would be required to participate under the Waxman-Markey proposed CO_2 cap-and-trade program.

Figure 3-1 shows a representation of the possible dynamics of the cap-and-trade policy. For the purpose of this thesis, we will assume that the same policy structure will be implemented in the three analyzed regions; U.S., E.U., and China.

CO_2 Cap-and-Trade Diagram

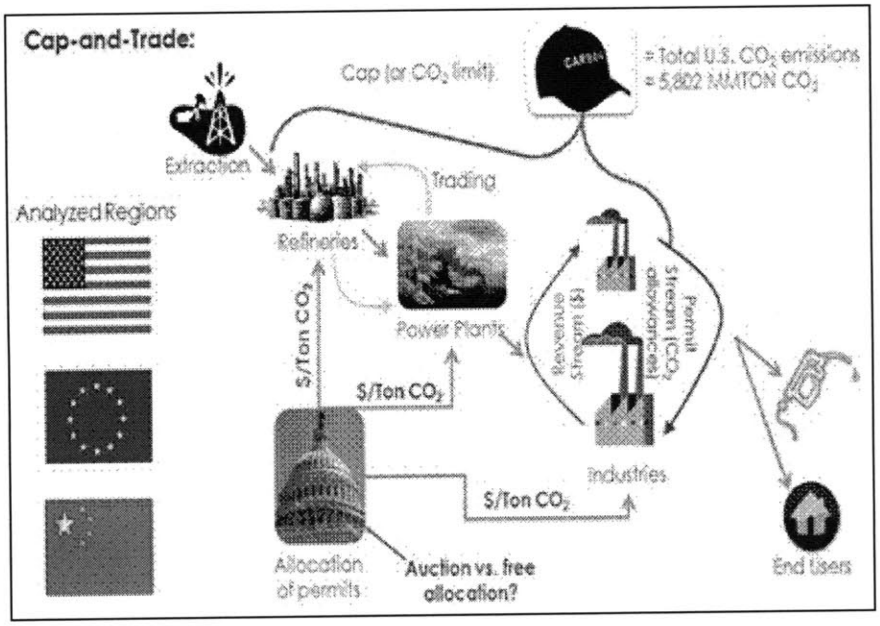


Figure 3-1: Diagram of cap-and-trade dynamics for the main regions of analysis; US, EU, and China. All entities emitting more than 10,000 tons of CO_2 per year will be mandated to participate in the cap-and-trade program.

3.1.1 EU ETS Case Study

To meet its obligations to reduce GHG concentrations under the Kyoto Protocol, the European Union (EU) established the first cap-and-trade system for CO_2 emissions in the world starting in 2005 (Joskow, 2008). Proposed in October 2001, the EU's Emissions Trading System (EU ETS) was up and running just over three years later. The first three-year trading period (2005-2007)—a trial period before Kyoto's obligations began—is now complete and, not surprisingly, has been heavily scrutinized. The following section describes the implementation successes and failures and lessons learned from the EU ETS case.

The development of the EU-ETS has not, however, proceeded without its challenges, as for example:

- Due to a lack of accurate data in advance of the program, allowances to emitters were over allocated. Now with more accurate emissions data and a centralized cap-setting and reporting process, the emissions cap should be sufficiently binding.
- Concerns about program volatility emerged when initially high allowances prices (driven largely by high global energy costs) dropped precipitously in April 2006 upon the release of more accurate, verified emissions data. Late in the trial phase, there was another sharp decline in allowance price because there were no provisions for banking emissions reductions for use in the second phase of the program. Improved data quality and provisions for unrestricted banking between compliance periods will help moderate price fluctuations in the future.
- Windfall profits by electric power generators that passed along costs (based on market value) of their freely issued allowances resulted in improved understanding of how member country electricity sector regulations affect the market and calls for increased auctioning in subsequent phases of the program.

The performance of the European Union's Emissions Trading System (EU ETS) to date cannot be evaluated without recognizing that the first three years from 2005 through 2007 constituted a "trial" period and understanding what this trial period was supposed to accomplish. Its primary goal was to develop the infrastructure and to provide the experience that would enable the successful use of a cap-and-trade system to limit European GHG emissions during a second trading period, 2008-12, corresponding to the first commitment period of the Kyoto Protocol. The trial period was a rehearsal for the later more serious engagement and it was never intended to achieve significant reductions in CO_2 emissions in only three years.

Although there have been plenty of rough edges, a transparent and widely accepted price for tradable CO_2 emission allowances emerged by January 1, 2005. A functioning market for allowances has developed quickly and effortlessly without any prodding by the Commission or member state governments, the cap-and-trade infrastructure of market institutions, registries, monitoring, reporting and verification is in place, and a significant segment of European industry is incorporating the price of CO_2 emissions into their daily production decisions.

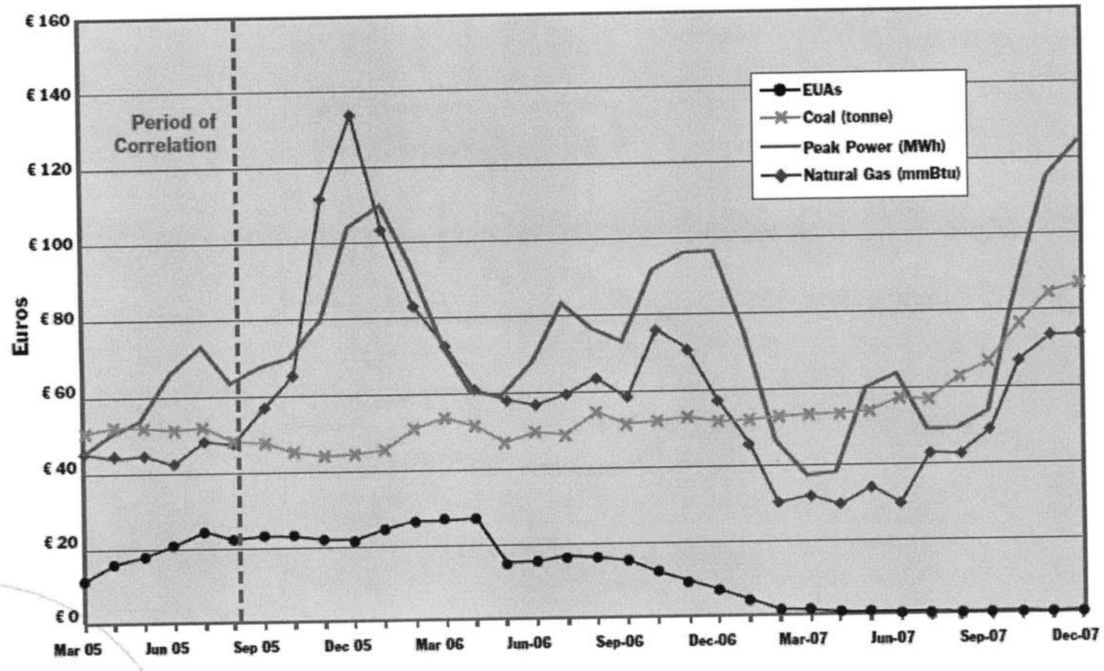
The development of the EU ETS and the experience with the trial period provides a number of useful lessons for the U.S. and other countries:

- Suppliers quickly factor the price of emissions allowances into their pricing and output behavior.
- Liquid bilateral markets and public allowance exchanges emerge rapidly and the "law of one price" for allowances with the same attributes prevails.
- The development of efficient allowance markets is facilitated by the frequent dissemination of information about emissions and allowance utilization.

3.2 Price Dynamics for CO_2 Policies

The increase in electricity prices that was experienced in Europe during the first year of the EU-ETS imparted much impetus to the windfall profits controversy. Yet much of that price increase was due to increased fuel prices, as shown by Figure 3-2, which tracks the evolution of spot or near-term prices for coal, natural gas, CO_2 and electricity. There was a brief period during the first seven months of 2005 (to the left of the dotted line in Figure 3-2) when electricity and EUA prices moved together. Electricity prices increased from about €40 per megawatt-hour (MW-h) in early 2005 to €70 per MW-h by the summer at the same time that EUA prices went from about €10 per metric ton to over €20, while fuel prices remained relatively unchanged. Thereafter, peak electricity prices rose to as much as €110 per MW-h, but their movements were far more closely related to the price of natural gas than to that of EUAs. And since spring 2007, electricity prices have increased from €40 per MW-h to over €120 per MW-h in keeping with fuel costs and at a time when the CO_2 price has been insignificant.

Prices for Electricity, Coal, Natural Gas and EUAs; 2005-2007



Source: Compiled by the authors from *Tendances Carbone.*

Figure 3-2: Correlation between prices of EUAs and main energy commodities from: 2005-2007

Once the concept of opportunity cost is understood, the issue of how CO_2 allowance prices are "passed through" in the final prices for electricity or for other goods and services must be addressed. The extent to which allowance prices are reflected in the prices of final goods is a complicated matter even when markets are fully competitive. In theory, and in a perfectly competitive market, the marginal supplier that clears the market will pass through that supplier's full marginal (acquisition or opportunity) cost of allowances per unit of output. Infra-marginal[10] suppliers will be affected in different ways depending on their CO_2 intensities and whether or not they must purchase allowances to cover their emissions. However, in real electricity markets, there are many conditions that can lead to more or less than full pass-through of marginal costs. Finally, to the extent the market is not perfectly competitive, the full carbon cost will not be passed through and some degree of previous oligopoly profit will be given up as firms adjust to the new cost circumstances.

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[10] These are suppliers used before the last generator to supply electricity.

Research conducted by Jos Sijm at the Energy Research Centre of the Netherlands and his collaborators finds that CO_2 costs have been passed through to wholesale electricity prices but that generators have not been able to recover the full market value of their free allocations. In a careful study of wholesale electricity markets in Germany, the Netherlands, Belgium and France from January through July 2005, (J. Sijm, 2005) estimated that the average pass-through rates varied from 40 percent to 70 percent depending on the country and whether it was a peak or off-peak demand period.

Whatever the effect of CO_2 costs on wholesale electricity prices, the effect on retail customers depends on the degree of liberalization[11] in retail markets. In many EU member states and for many customer categories, retail power prices continued to be regulated based on historical costs rather than wholesale market prices. For instance, in Spain, the increase in retail prices for regulated customer classes was limited to a set percentage increase and any greater cost incurred by generators for fuel or CO_2 allowances is booked as a regulatory asset to be recovered later. Moreover, the Spanish regulator has recently stated that companies would not be able to recover the opportunity costs of freely allocated allowances. What can be generally said is that, for retail customers in many member states although not all, the higher wholesale prices resulting from CO_2 emissions costs have not been passed through. Large industrial customers are more likely to have faced retail prices reflecting higher wholesale electricity prices, although for these customers as well, much depends on the progress of market liberalization in each member state. Even so, as pointed out in a study on this subject conducted by the International Energy Agency (IEA, 2007), large industrial customers are often protected by long-term contracts and other financial means of hedging wholesale power price volatility.

The EU ETS is also interesting because it provides some insights into the problems to be faced in constructing a global GHG emission trading system. This will be the next stage in global climate diplomacy if and when the U.S. adopts a cap-and-trade system. In imagining a multinational

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[11] This refers to the liberalization of electricity markets, from more vertically integrated and regulated to more market-based competition oriented.

system, it seems clear that participating nations will retain significant discretion in deciding tradable national emission caps albeit with some negotiation. Separate national registries will be maintained with some arrangement for international transfers; monitoring, reporting and verification procedures will be administered nationally although necessarily subject to some common standard; and it seems doubtful that internal allocations will be "harmonized". As the world moves to develop and to link GHG trading systems, challenges similar to those characterizing the EU ETS will have to be confronted.

The deeper significance of the trial period of the EU ETS may be that its explicit status as a work in progress is emblematic of all climate change programs. Even when not enacted in haste, climate change programs will surely be changed over the long horizon during which they will remain effective. The trial period demonstrates that everything does not need to be perfect at the beginning. In fact, it provides a reminder that the best can be the enemy of the good. And this adage is likely to be especially applicable in an imperfect world where the income and wealth effects of proposed actions are significant and sovereign nations of widely varying economic circumstance and institutional development are involved. The initial challenge is simply to establish a system that will demonstrate the societal decision that GHG emissions shall have a price and to provide the signal of what constitutes appropriate short term and long-term measures to take in limiting GHG emissions to the desired amounts. In this, the EU has done more with the ETS, despite all its faults, than any other nation or set of nations.

3.3 CO_2 Tax Policy

The CO_2 tax is another possible policy tool that can be implemented in order to reduce the impact of GHG emissions and global warming. With a carbon tax, a tax is placed on fossil fuel producers or importers at a rate that reflects the amount of carbon that will be emitted when the fuel is burned or used. That tax would likely be levied at the first point of transaction from producer/importers to users (utilities, manufacturers, carriers), increasing the fuel price. So, market mechanisms in theory should drive users away from more carbon-intensive fuels to more carbon-efficient ones, or to find ways to reduce their costs by using less of a given fuel. The tax would be based on carbon emissions per BTU, which are precisely known. As such, coal would likely have by far the highest tax, followed by oil in the middle and finally natural gas, which has a very favorable BTU to emissions ratio. Provisions would be made to exempt fossil fuels that are used in non-carbon emitting applications (e.g., oil used in making plastics).

In terms of structure and implementation, a tax policy is simpler than a cap-and-trade policy to implement and follow. Nevertheless, this option has a lot of opposition from several stakeholder groups, namely tax payers and environmentalists. A "tax" policy in the U.S. is very unlikely to gain popular demand because of the people aversion to pay additional taxes and because the dislike of many environmentalist. One of the main reasons for dislike among environmentalists is the lack of certainty about targeted emissions reduction that exist in a CO_2 tax policy (see Table 3-2). Because of the US polarity towards a Cap-and-Trade, the CO_2 Tax discussion will be minimal, focusing the efforts on Cap-and-Trade dynamics.

3.3.1 Scandinavian Countries Case Study

Environmental taxes have been in place in several countries since the early 1990s, but the experience is mixed (Prasad, 2008). For example, although carbon taxes have been implemented in every Scandinavian country, no country other than Denmark has seen large declines in CO_2 emissions. Some have seen decreases in energy intensity (CO_2 emissions per unit of per capita GDP), but the worst performer, Norway, has seen a 43 percent increase in CO_2 emissions as well as rising energy intensity (Table 3-1—Finland's large decreases have come only in the last two years of the series, and it remains to be seen whether they are sustainable). Although it is difficult to measure the effectiveness of carbon taxes, case studies accounting for factors such as changes in the sectoral composition of the economy and attempting to compare current emissions against the counterfactual of what would have been the case in the absence of the tax likewise suggest much greater success in Denmark than in

Norway or Finland (Enevoldsen, 2005 on Denmark; Bruvoll and Larsen, 2004 on Norway; Vehmas, 2004 on Finland; and see especially (Enevoldsen, Ryelund, and Andersen 2007 on Denmark, Norway, and Sweden). Speck et al. (2006) summarizes studies that show that in all countries, emissions are lower than they would have been without the tax, but that emissions reductions are much more significant in Denmark.

Table 3-1: CO_2 intensity growth rate comparison: Scandinavian and US

	Growth in CO_2 Emissions per Capita, 1990-22005, (%)	Growth in Energy Intensity (tons of CO_2 emissions per unit of per capita GDP), (%)
Denmark	-14.77	-31.26
Finland	-5.93	-24.74
France	4.77	-7.20
Netherlands	19.14	-1.61
Norway	43.03	5.18
Sweden	4.40	-15.36
US	0.73	-8.92

Source: Energy Information Administration, International Energy Annual

Taxes on energy were first implemented in the Scandinavian countries in the wake of the oil crisis, as a means of promoting energy independence. Denmark is the only country to have seen a large decline in CO_2 emissions between 1990 and 2005, adding up to nearly 15 percent lower CO_2 emissions. Did Denmark sacrifice economic growth to achieve its environmental objectives? It is possible that growth would have been even higher without the tax, but Denmark has posted a remarkably strong economic record since 1993, to the point that some speak of a "Danish miracle". The decline in total CO_2 emissions in Denmark has been driven by a decline in CO_2 emissions from coal (Figure 3-3)—petroleum consumption is basically stable, having returned to 1990 levels from a mid-90s peak and natural gas consumption has risen steadily. Because 90 percent of coal products are consumed in the manufacturing sector in Denmark, the decline of coal—and thus the decline of CO_2 emissions in Denmark, the only country to have seen CO_2 emission decline on this scale—is largely a story of Danish manufacturing reducing its use of coal and coal products. Denmark has traditionally had a very small nationalized sector, and over 99 percent of manufacturing firms are privately owned, so the decline cannot be explained by the actions of state-owned enterprises: it is private firms that have been making the decision to move away from coal (Paldam, 2003).

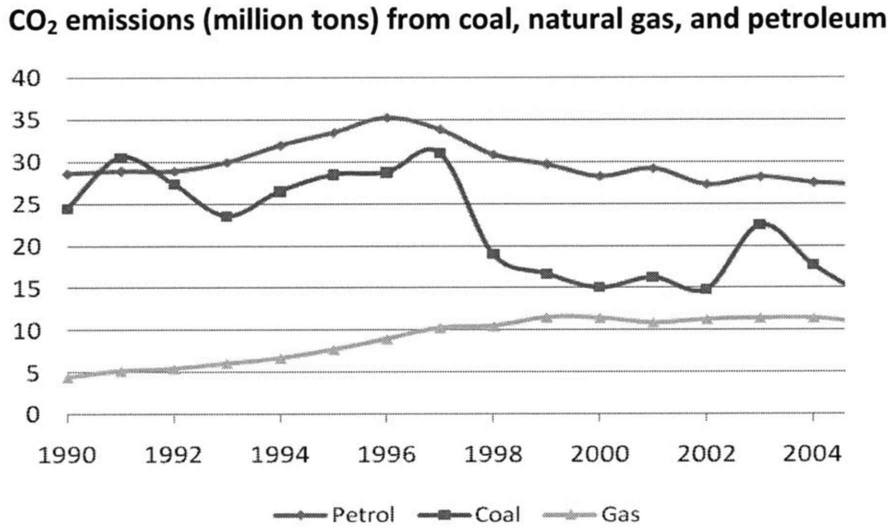

Figure 3-3: Total CO_2 emissions in Denmark from 1990 to 2005[12]

The lessons from the case study of Scandinavian green taxes cannot literally be applied to the U.S.: the gains from wind power, for example, are greater for Denmark because of its geographic location. But it is possible to apply the general principles of providing substitutes, targeting the revenue to environmental aims, and taxing firms rather than households. It was the first of these three principles that received the strongest support from the Danish case, suggesting that the clearest lesson of this study is that green taxes should be levied on products that have substitutes (or coupled with policies to provide substitutes, such as lower taxes on a "cleaner" alternative). Some social process of coordination, such as industry-wide agreements, can prod firms to make the substitution. In addition, the case study suggests that policymakers should avoid the trap of looking for a "double dividend". Actual revenue collected is a signal that the tax has failed in its regulatory aims, indicating that the state should use those revenues to reach the aims in some other way (such as funding research into alternative energy sources,

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[12] EIA.gov, International Energy Annual

or subsidies for firms that undertake projects to improve energy efficiency); this will also avoid giving incentives to state actors to use the tax for revenue raising purposes. And finally, although the evidence is less clear here, governments should perhaps tread cautiously during this moment of worldwide norm creation, avoiding the imposition of taxes on those who are behaving in altruistic ways to protect the environment for fear of permanently crowding out their ethical motivations; this suggests that firms, rather than households, are a better target when deciding whom to tax, because households may be more likely to be altruistically motivated than firms.

3.4 Comparing the Two Approaches: Cap-and-Trade vs. Tax

The following Table 3-2 summarized the main carbon price policies (cap-and-trade and tax) by six main sub-sections. The table is copied from the Supply Chain Digest – Green SCM: the green supply chain 360°, Preparing Supply Chains for the Green Future; Understanding Cap and Trade and Carbon Taxes.

Table 3-2: Summary comparison between Cap-and-Trade and Tax[13]

	Cap-and-Trade	Tax
Emissions Certainty	Can set firm limit on emissions - though politicians may continually back off	Not directly mandated, but taxes could be set at levels expected to deliver a given reduction in CO_2 over time. In good economic times, for example, an industry as whole or specific companies may simply decide to pay the tax and meet market demand for products.
Price Predictability	Prices for emissions permits fluctuate in an open market, which can cause some real planning challenges for business and lead to emergency "changes" in the rules.	The tax level is fixed, absent legislative changes. Business will know exactly how much energy purchase/consumption will cost.
Incentives for Investment	Because the cost of emissions is more volatile, investments in new technologies to reduce emissions would likely be constrained by lack of clarity about ROI.	As the cost of the tax is fixed, this would enable business to make more informed and confident investments to reduce CO_2 emissions - but the ROI will depend on the level of the tax.
Overall Effectiveness	Is highly dependent on the details of how aggressively the caps are phased in, how permits are created and distributed, and other factors.	Probably less subject to political manipulation, but the level of tax needed to make an impact is not well understood, and it is not clear if politicians would be willing to go that far anyways.
Simplicity and Transparency	Requires new administrative structures, new "Wall Street" market mechanisms to trade the permits, and some way to actually measure and monitor emissions. Also likely more susceptible to political forces over time.	Would be an add-on to existing tax structures and collection procedures. Most believe a carbon tax is much simpler for consumers and business to understand.

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[13] Taken from www.thegreensupplychain.com, Supply Chain Digest – Green SCM: the green supply chain 360°, Preparing Supply Chains for the Green Future; Understanding Cap and Trade and Carbon Taxes. (2009)

(cont.)	Cap-and-Trade	Tax
Time to Results	The inherent complexity likely means it will take fairly long to set up all the mechanisms and achieve results - as Europe's experience attests.	Could in theory be implemented much faster - but would impact behavior only at levels where the government may fear to go.

.5 CO_2 Policies and Treaties Timeline: US and Worldwide

ure 3.4 shows a summary of past and future CO_2 policies and treaties in the US and worldwide.

	2005	2007	2008	2009	2010	2012	2020	2
al o kes an	"Trial Phase" of the Kyoto Treaty starts (i.e. EU ETS)	End of "Trial Phase" for the Kyoto Treaty	Start of the Kyoto Protocol "GHG Reduction Phase", 5% below 1990 CO_2 levels	The US House of Representative vote in favor of the Waxman-Markey Bill in June A follow-up for 2012 deadline of the Kyoto Protocol is taking place in Copenhagen, Denmark on December No legally binding document agreement was reach in Copenhagen	The US Senate version of the House bill, Kerry-Boxer, will be brought to the Senate floor for a vote. UN meeting in Mexico City this November. Negotiators hoping the US will have committed to domestic targets by then	End of the Kyoto Protocol Treaty from year 2008 Start of the Copenhagen Climate Treaty 2009 (Kyoto follow-up)	End of 1st phase of the Copenhagen Treaty, 17 - 20% below 2005 CO_2 levels	Deadli reduce GHG b below levels t potent irrever climat

Figure 3-4: **CO_2 policies and treaties timetable**

3.6 Chapter Summary

CO_2 (or Carbon) Cap-and-Trade is a market based mechanism that identifies emitting entities, sets a cap on total emissions, distributes emissions allowances to covered entities that in total equal the cap, requires entities to turn in allowances equal to their emissions in each period (e.g., year), and allows trade so that a market for and a price or emissions allowance is established.

The EU, through their ETS, demonstrates that a potential international cap-and-trade policy can take place. They are presented with some difficulties in their implementation, which was totally foreseeable, taking into account they are the first country/region implementing such a sophisticated and complex policy mechanism. Much care needs to be put in avoiding wind-fall-profits from the private sector.

A CO_2 Tax is a policy instrument that places a tax on fossil fuel producers or importers at a rate that reflects the amount of carbon that will be emitted when the fuel is burned or used. That tax would likely be levied at the first point of transaction from producer/importers to users (utilities, manufacturers, carriers), increasing the fuel price. So, market mechanisms in theory should drive users away from more carbon-intensive fuels to more carbon-efficient ones, or to find ways to reduce their costs by using less of a given fuel.

On the other hand a case study is discussed for the tax implemented in the Scandinavian countries. The case study shows significant variation from country to country results, e.g. between Denmark and Norway. Denmark achieved 14 percent decreases of CO_2 per capita while Norway increased it around 43 percent.

The main differences between the two policy options are highlighted. In conclusion, the Tax policy is easier for implementation but the Cap-and-Trade policy targets in a more direct way the amount of CO_2 to be permitted into the atmosphere. Copenhagen 2009 Climate Summit is not capable of bringing US and China to agree in a legal binding document restraining GHG emissions. The US Senate climate and energy bill, Kerry-Boxer, will be brought to the Senate floor for debate in April 2010.

4. DELL'S SUPPLY CHAIN CO_2 FOOTPRINT APPROACH

The following chapter defines and explains the supply chain and product under study. It also discusses the main frameworks used to perform the LCA and the assumptions to make the analysis.

4.1 Industry Approach

A "Process-Sum" LCA was performed for the specified supply chain described in Figure 4-1 in order to calculate CO_2 emissions per notebook. The boxed segment (from suppliers to transportation II) defines the boundaries of the process-sum analysis. The data used for this analysis was gathered from several public and private (Dell) databases. No actual measure for electricity use, manufacturing process energy intensity, transportation related emissions or other data is physically performed by the author. All results were calculated from the data provided by these other sources.

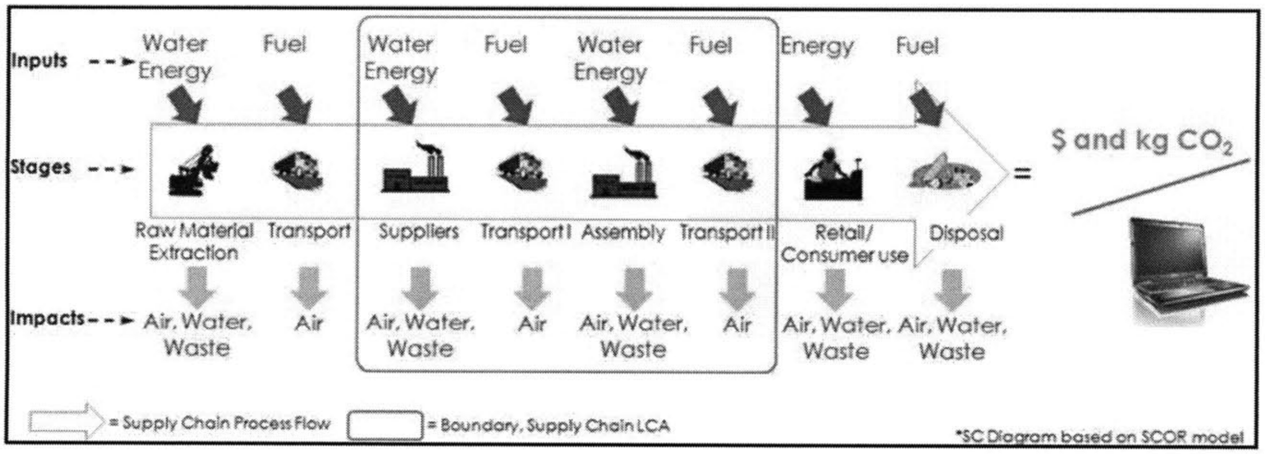

Figure 4-1: Supply Chain segments directly related to Dell's operations.

4.1.1 Green SCOR[14]

The Supply Chain Operations Reference (SCOR) Model, a global standard for supply chain projects developed by the Supply Chain Council, has been updated to address environmental sustainability efforts while expanding risk management capabilities. SCOR version 9.0 incorporates GreenSCOR (LMI Consulting, 2008), which had served as a standalone reference model. The GreenSCOR capabilities include:

- Industry best practices for making the supply chain more environmentally friendly, such as collaborating with partners on environmental issues, reducing fuel and energy consumption, and minimizing and reusing packaging materials.
- Metrics to measure the effects of greening, including carbon and environmental footprint, emissions costs per unit, energy costs as a percent of production costs, waste produced as a percent of product produced, and returned products disposed of versus remanufactured.
- Processes to address waste management, such as how to collect and manage waste produced during production and testing (including scrap metal and nonconforming product).

GreenSCOR framework was used as the standard procedure to identify the different steps of Dell's end-to-end supply chain for the studied scenario.

4.1.2 GHG Protocol[15]

The Greenhouse Gas Protocol (GHG Protocol) is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. It provides the accounting framework for nearly every GHG standard and program

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[14] GreenSCOR is a set of environmental sustainability metrics included in the already proven SCOR method to asses environmental sustainability of supply chain networks.

[15] http://www.ghgprotocol.org/

in the world - from the International Standards Organization to The Climate Registry - as well as hundreds of GHG inventories prepared by individual companies.

This organization has different standardized procedures for customized processes:

- Product and Supply Chain
- Project Protocol
- Corporate Standard

For the purpose of this study, the Product and Supply Chain standard was used. This standard includes:

1) Product Life Cycle Accounting and Reporting Standard: The goal of the GHG Protocol Product Standard is to support public reporting of product life cycle greenhouse gas (GHG) emissions to help companies and other organizations reduce these emissions by making informed choices about the products they design, manufacture, sell, purchase or use.

2) Scope 3 Accounting and Reporting Standards: These are indirect emissions associated with your company's activities and include for example: production of purchased materials, product use, outsourced activities, employee business travel, and contractor owned vehicles.

The final analysis was done using these two methods for different objectives. The GreenSCOR was used specifically to identify the different steps of Dell's SC. The GHG Protocol was used to account for the CO_2 footprint on each of the defined SC steps.

4.2 Approach to Calculate CO_2 Footprint

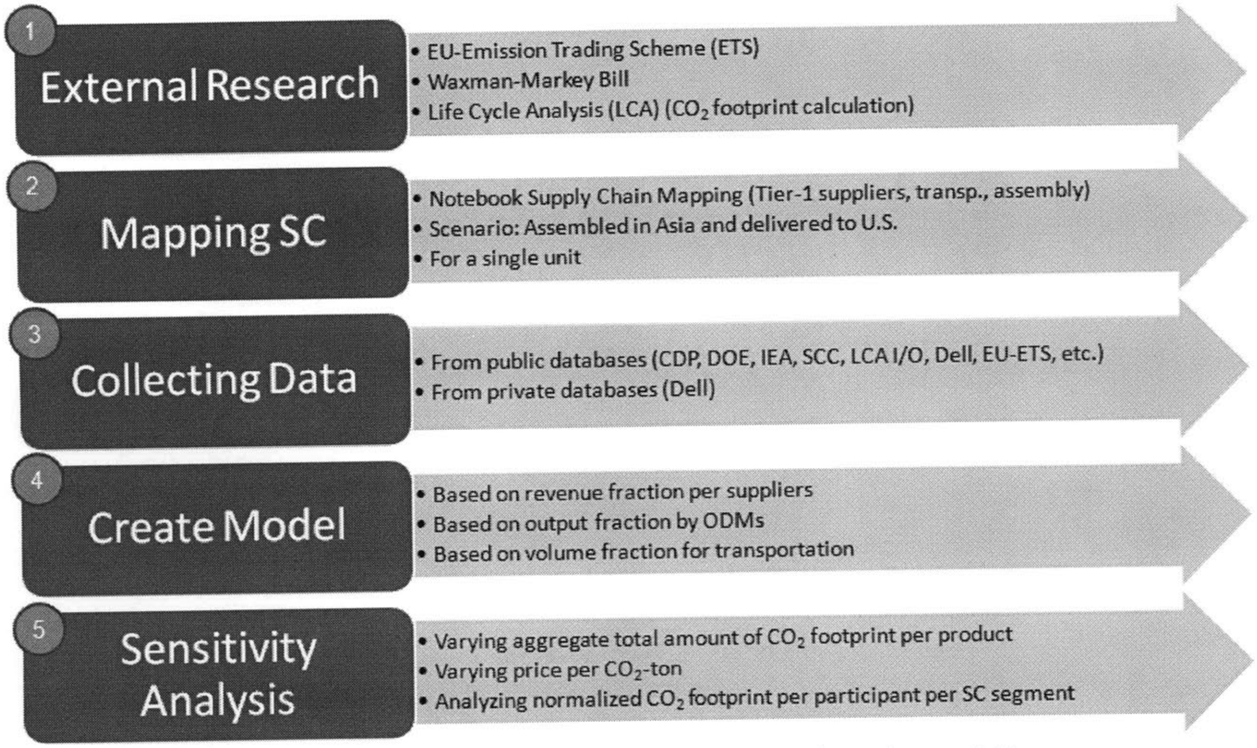

Figure 4-2: Project framework and the main steps through completion.

Figure 4-2 summarizes the framework of this project. The first step is gathering information (mainly policy papers) from publicly available data sources. Some of those sources included the EU-ETS, the Waxman-Markey Bill (passed by the U.S. House of Representatives), and some case studies on reported LCA calculations. The next step is mapping out (see Figure 4-1) the supply chain network for the notebook under study. This includes tier-1 suppliers, transportation, and assembly for a laptop assembled in China and delivered to the U.S. After knowing the specific supply chain network, we started data collection, which was done using both private and public databases. Once the data is obtained, a model is created to calculate the final footprint per notebook. The CO_2 fraction allocated to Dell's notebook is derived from revenue ($) fraction per suppliers, output fraction per ODMs and volume fraction for the transportation phase (more details in Chapter 5). Lastly, a sensitivity analysis is performed in order to account for the variability and errors in the data. A range of possible outcomes is presented in this study's final results.

4.3 Chapter Summary

Two principal methods are used to help define and segment Dell's notebook supply chain and to allocate the CO_2 per supply chain steps, GreenSCOR and GHG Protocol, respectively. A description of these two methods is provided for the understanding of the reader. An in-situ framework is created by the author to standardize the LCA research process. The next chapter will expand on the main assumptions and calculations utilized for each of the SC steps shown in Figure 4-1.

5. METHODOLOGY

This section explains the process of data collection and the sources used in this study, which were the main assumptions of the analysis, in more detail. As previously specified in Chapter 4, Figure 4-1, LCA was calculated using a process-sum (real available data for the specifics SC segments) method with available data from public and private (Dell) sources.

5.1 Main Assumptions

The main global assumptions for this project are the following: **1)** the footprint for the notebook is calculated with a final unit of CO_2 per notebook, not $CO_{2\text{-equivalent}}$ ($CO_{2\text{-e}}$); **2)** Manufacturing data includes: Tier-1 suppliers and assembly. Raw material, Tier-2 and Tier-3 suppliers, and end-of-life footprints are not calculated due to complexity and total lack of data; **3)** 100 percent of suppliers' CO_2 cost attributable to Dell is allocated to Dell; and **4)** by year 2012 air carriers start charging for CO_2 emissions.

5.2 Supply Chain Hybrid Model Data Acquisition Sources

Table 5-1 describes how the main SC components were calculated, and the main source of data. The following sub-section, 5.2.1, explains each SC step in more detail.

Table 5-1: Main LCA supply chain components and information sources

SC Steps		Main Info Source
Tier-1 Suppliers	Process-Sum	Carbon Disclosure Project
Transportation I	Process-Sum	Fuel Consumption Estimates (Murty, 2000)
Assembly	Process-Sum	Dell Internal Database
Transportation II-A	Process-Sum	Fuel Consumption Estimates (Murty, 2000)
Transportation II-B	Process-Sum	EPA Rail/Truck Emissions Estimates
Use	Process-Sum	Dell Web Footprint Calculator

In Table 5-1, we show that the CO_2 footprint per notebook derived from Tier-1 suppliers was calculated using a process-sum model from available data from the Carbon Disclosure Project (CDP).[16] It is important to mention that even the "process-sum" data was not physically measured by the author at any SC stage but rather taken from private or publicly available data sets. Some of these data sets are not verified by a third party. This adds to the uncertainty of the process.

5.2.1 Product Analysis – Notebook Overview

The analyzed product for this study is a 15-inch notebook, with a 5,400 RPM disk drive, DVD/CD combo, 4GB of memory and Energy Smart Power Management setting[17]. The main components taken into consideration for the notebook assembly are the following:

- Memories
- CPU
- Chipsets
- LCD Panel
- Battery

It is important to mention that the collected data was from the publicly available non-third-party certified, CDP. The unit presented in the CDP is ton-CO_2/year. This is then converted to ton-CO_2/NB.

5.2.2 Tier-1 Suppliers

This is estimated from a publicly available data base (CDP, 2003). A list of every notebook Tier-

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[16] The Carbon Disclosure Project is an independent not-for-profit organization holding the largest database of primary corporate climate change information in the world. https://www.cdproject.net/en-US/Pages/HomePage.aspx

[17] Energy Smart has the following settings: 1) time out to sleep (hrs) = 0.25, 2) time out to hibernate (hrs) = 4 and 3) monitor time out (hrs) = 0.25

1 supplier is provided to the author in order to make this analysis. This data provides all Tier-1 suppliers' revenue for the year 2008 and Dell's fraction for each supplier. Using this data we calculated how many suppliers represent 80 percent of Dell's procurement cost. It comes out that only six suppliers account for 80 percent of Dell's total Tier-1 suppliers' cost. The bottom 20 percent of the CO_2 by Tier-1 suppliers was calculated from the CO_2 ton of the top six suppliers (i.e. 1.20 x Total CO_2 tons from top six Tier-1 suppliers). We obtain the total CO_2 emissions of those six suppliers from the publicly available database from the CDP. Table 5-2 shows the top six suppliers, their total CO_2 footprint published on the CDP database and Dell's total allocated fraction per supplier.

Table 5-2: Top Tier-1 suppliers CO_2 allocation to Dell

Supplier	Commodities	Suppliers CO_2 (metric tons)	Dell's allocated CO_2 (metric tons)
Intel Corp	CPU, Chipset	3,870,000	596,804
Kingston Tech	Memory	3,800,000	243,983
Hynix Semiconductor	Memory	3,717,000	226,658
Nanya Technology	Memory	742,595	156,506
Samsung Electronics	Memory, LCD, RMSD, Battery	7,096,772	136,819
Seagate Technologies	Hard Disk Drive	936,842	87,449

As previously mentioned, this CDP data is non-third-party verified. The CO_2 presented in Table 5-2 only accounts for what is known as Scope 1 and Scope 2 based on the GHG Protocol. The GHG Protocol defines these emissions as follow:

- Scope 1: All direct GHG emissions.
- Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.
- Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

Now that the top 80 percent of CO_2 emissions from Tier-1 suppliers has been calculated for Dell, the next step is to allocate it on a per notebook basis. For this allocation, a 1:1 ratio of components-to-notebook is assumed due to lack of data and for simplicity purposes. This adds uncertainty to the final result and will be taken into account by the sensitivity analysis discussed further in this document. This ratio varies not only for notebooks, but for desktops, servers, and power stations.

It was not possible to obtain the exact ratios of components-to-Dell products. For the analyzed time-frame, 2.93 million notebooks of the specified model in this study were sold in the United States, representing about 15 percent of the total sold notebooks worldwide by Dell and seven percent of the total portfolio of product units sold by Dell. The following Equation 1 shows the calculation process for suppliers' CO_2 allocation.

$$\text{(Total Top 6 Suppliers } CO_2\text{-Tons)} \cdot \text{(\% of NBs)} \cdot (1.2) \cdot \text{(1,000 kg/Ton)} = \mathbf{X}\ \text{kg-}CO_{2\text{-total}} \qquad \text{Eq. (1)}$$

$$\Rightarrow \text{ To get the total kg-}CO_2\text{ per notebook} = \text{X kg-}CO_{2\text{-total}} \div \text{Total NBs} = \boxed{\text{Y kg-}CO_2\text{/NB}}$$

5.2.3 Transportation-I

We defined transportation-I as the transportation that takes place from Tier-1 component suppliers to Dell/ODMs assembly facilities. The author was able to collect actual data from suppliers and assembly locations and modes of transportation. With this data and energy intensity coefficient for transportation modes, the CO_2 intensity was calculated. Table 5-3 shows the list of locations, distances, transportation modes, emission factors and CO_2 emissions.

Table 5-3: Transportation I variables and calculated CO_2 emissions

Supplier	Distance to assembly facility (km)	Transportation mode	Total CO_2 emissions	Kg/component	Kg-CO_2/NB
Intel	14,796	Airplane	652.5	0.675	1.10
Intel	0	Truck	0	0.675	0
Intel	3,709	Airplane	163.6	0.675	0.28
Intel	2,772	Airplane	122.3	0.675	0.21
Kingston	773	Airplane	34.1	0.102	0.03
Hynix	951	Airplane	41.9	0.102	0.04
Nanya	773	Airplane	34.1	0.102	0.03
Samsung	951	Airplane	41.9	0.102	0.01
Samsung	0	Truck	0	0.102	0
Samsung	2,772	Airplane	122.3	0.102	0.04
Seagate	0	Truck	0	0.165	0

An emission factor of 3.15 ton-CO_2/ton fuel, an airplane fuel density of 0.8kg/L and an airplane burn rate of 17.5 L/km was used to calculate the total CO_2 emissions from the data in Table 5-3 (for a Boeing 747). All these coefficients vary from flight to flight, adding more uncertainty to the final result. The truck transportation in Table 5-3 is assumed to have negligible CO_2 emissions relative to the airplanes. The emissions associated with Intel and Samsung were divided by the number of locations for each company. For example, each of Intel's four different locations is assigned with 25 percent of the total emissions. This is based on the fact that the company ships its components from each of its facilities based on availability, with no regards to location. The same is assumed with Samsung, but at 33 percent. Equation 2 shows how total emissions of CO_2 per one-way air trip are determined.

$$\frac{\left(\text{burn rate}\left({}^{\mathrm{L}}/_{\mathrm{km}}\right)\cdot\left(\text{fuel density}\left({}^{\mathrm{kg}}/_{\mathrm{L}}\right)\right)\cdot\left(\text{distance (km)}\right)\cdot\left(\text{carbon intensity}\ {}^{\mathrm{ton}-\mathrm{CO_2}}/_{\mathrm{ton}-\mathrm{fuel}}\right)\right)}{1{,}000\ {}^{\mathrm{kg}}/_{\mathrm{ton}}} \qquad \text{Eq. (2)}$$

The kg per component number shown in Table 5-3 is calculated from an average assumed range of weight per component. The following Equation 3 shows how the kg-CO_2/NB is determined for Transportation I.

$$f_{supp} \cdot \left(\frac{\frac{kg}{notebook} \cdot 1.5}{kg-payload}\right) \cdot (CO_2\text{-tons} \cdot 1000kg/ton) = kg\text{-}CO_2/NB \qquad \text{Eq. (3)}$$

Where; 1) f_{supp} is the fraction based on total locations by suppliers (e.g. 25% for Intel, 0.33 for Samsumg); 2) the 1.5 is a safety factor in order to account for the components' packages weight; 3) the payload is defined as the total weight of cargo that an aircraft can carry, and; 4) the CO_2-tons are the tons that are emitted from the aircraft combustion process to the atmosphere.

5.2.4 Final Assembly

Final assembly of this notebook takes place in China. The production is split between five facilities, all of which are ODM (non-Dell factories). Much of their plant capacity data, and electricity and energy consumption are not easily accessible to outsiders (i.e. this study). The singular purpose of these facilities is to assemble the components into the final notebook. These facilities are not electronic component manufacturers (i.e. chips, Si wafers, HD, etc). This kind of component manufacturing is allocated in the Tier-1 supplier SC segment. In order to estimate the electricity consumption for each of the five facilities, a derived calculation is done from similar size Dell-owned facilities. The capacity of each ODM, obtained in some cases, and calculated (from Dell facility data comparisons) in others for Table 5-4, shows the final calculated numbers for capacity output per ODM facility, allocated capacity to Dell notebooks, electricity consumption, carbon intensity and final CO_2 footprint allocated per notebook.

Table 5-4: CO_2 emissions calculation from finished good assembly facilities

Facility	Capacity (units/yr)	Electricity consumption (kWh/yr)	Carbon intensity (kg-CO_2/kW-hr)	Kg CO_2/notebook
ODM 1	6,804,000	15,000,000	0.794	1.75
ODM 2	3,640,000	11,250,000		2.45
ODM 3	2,272,000	7,000,000		2.45
ODM 4	88,000	1,000,000		9.02
ODM 5	88,000	1,000,000		9.02

Note: Facility names/locations are misguided for confidential purpose. Data is real.

An average allocation of the CO_2 emitted by electricity consumption is used among the entire capacity per facility due to lack of access to detailed information. The carbon intensity is used from IEA estimates about average carbon intensity in China in year 2007.

5.2.5 Transportation-II (A and B)

We define transportation-II as the transportation that takes places for finished goods from the final assembly facilities in China to the final customer in the United States. We divide this transportation into two main segments: transportation II-A and transportation II-B. Transportation II-A is the air transportation that takes place from the final assembly facility to one of five U.S. destination airports. Transportation II-B is the ground transportation that takes place between one of the five U.S. airports to the final customer.

The locations of Asia's final assembly facilities and U.S. destination airport are known, and so the distance, CO_2 transportation intensity and transportation mode are also known, thus allowing for the calculation of CO_2 emissions. Table 5-5 shows the transportation II-A variables used to calculate emissions for this SC segment.

Table 5-5: Transportation II-A variables and data used to calculate CO_2 emissions

Traveled Distance (km) from Asia to U.S.	Tons of CO_2 (per single trip)	Allocated Kg-CO_2/notebook
10,295	454.0	28.7
10,821	477.2	30.1
11,143	491.4	31.0
11,627	512.8	32.4
12,627	553.3	34.9
12,867	567.4	35.8
12,495	551.0	34.8

As previously mentioned, an emission factor of 3.15 ton-CO_2/ton fuel, an airplane fuel density of 0.8kg/L and an airplane burn rate of 17.5 L/km was used to calculate the total CO_2. The method used to allocate kg-CO_2 for the transported notebook is based on volume capacity (instead of weight). By the time of this analysis, the most used method for shipping units was based on volume. On average, for each airplane shipment, Dell units take approximately 55 percent of the aircraft cargo volume. For the analyzed notebook, this represents around 8,640 notebooks per aircraft shipment. We allocated 55 percent of the total amount of CO_2 emissions for the entire traveled distance to Dell notebooks. Then we divided the 55 percent of total kg-CO_2 by the total average amount (8,640) of notebooks per flight. The following Equation 4 shows the process used to calculate the first row of Table 5-5.

$$\begin{gathered} 454.0 \text{ tons-}CO_2 = 454{,}000 \text{ kg-}CO_2 \\ 0.55 \cdot (454{,}000 \text{ kg-}CO_2) = 249{,}700 \text{ kg-}CO_2 \\ 249{,}700 \text{ kg-CO2} \div 8{,}640 \text{ notebooks} = 28.7 \text{ kg/nb} \end{gathered} \quad \text{Eq. (4)}$$

Transportation II-B takes place from the airport to the final ground destination. This represents a small fraction of the total transportation of the finished product. For the calculations of Transportation II-B, the following assumptions were made: the average ground distance traveled is 450 km and a CO_2 intensity (kg-CO2/Ton-km) of 0.14. Equation 5 shows an example of how this is calculated.

$$450\text{km} \cdot (0.14 \text{ kg-CO}_2\text{/Ton-km}) \cdot (\text{X ton/NB}) = \mathbf{Y} \text{ kg-CO}_2\text{/NB} \qquad \text{Eq. (5)}$$

5.2.6 Use phase

There are variations in the average kg-CO_2/kw-hr across the United States (EPA, 2007). This depends on the electricity power source mix for each region (i.e. coal having the greatest, then oil, gas, nuclear, renewables, etc.). Table 5-6 shows the list of states per region. We divided the U.S. into four main regions to account more accurately for these differences. The regions were divided by carbon intensity per unit of energy, and not by geographical region. Table 5-9 shows the complete set of assumptions used to calculate the emissions related to the use phase of this notebook. The use-life is set to 4-years.

Table 5-6: Average carbon intensity per electrical energy generation by U.S. region

Region I	Region II	Region III	Region IV
Avg. kg-CO2/kWh = **1.051**	Avg. kg-CO_2/kWh = **0.814**	Avg. kg-CO_2/kWh = **0.630**	Avg. kg-CO_2/kWh = **0.388**
Washington DC	Colorado	Montana	Arizona
North Dakota	Iowa	Nevada	North Carolina
Wyoming	Missouri	Nebraska	Pennsylvania
Utah	Kansas	Texas	South Dakota
Indiana	Delaware	Michigan	Virginia
Kentucky	Ohio	Mississippi	Louisiana
New Mexico	Oklahoma	Georgia	Illinois
West Virginia	Wisconsin	Florida	Alaska
	Hawaii	Alabama	Rhode Island
	Minnesota	Maryland	South Carolina
		Arkansas	New York
		Tennessee	New Hampshire
		Massachusetts	Maine
			Connecticut
			New Jersey
			California
			Oregon
			Washington
			Idaho
			Vermont

Dell website electricity usage calculator tool is used to compute consumed energy in the use phase (Dell, 2009). One significant problem with creating a tool such as this calculator is how to acquire the data necessary to calculate the annual energy consumption. With five different laptop models and an average of five selection options each, the number of possible system configurations addressed by the calculator is over three thousand per system chassis. Testing all these options using the described benchmark applications would require about 12,000 test hours to complete. In order to get around this test time dilemma Dell developed a mathematical model for system power consumption with systems and selection options represented as typical power consumption values. This data is collected and checked against a select subset of the total possible system configurations. Table 5-7 shows the default Dell model power management time values used in the calculator.

Table 5-7: Dell's power management time out values used in the calculator

	None	Default	Energy Smart	Energy Star
Time out to sleep (hrs)	Never	1	0.25	0.25
Time out to hibernate (hrs)	Never	Never	4	18
Monitor Time out	0.5	0.5	0.25	0.25

The number of work days in a year is defaulted to 250 days. Non-Work days are represented by using either the idle, sleep, or hibernate power for the entire 24 hours for the cases of no CPM and CPM enabled respectively. The calculator provides end users with the ability to configure the usage profile of the product. This allows the end user to describe the typical work load and annual usage of the product in his environment.

The calculator populates many fields with default values. These default vales are based on Dell usability experience and represent the typical usage of our products in an office environment. The default values simulate an eight hour work day with a one hour lunch at mid-day and morning and afternoon breaks. The work load for the day defaults to seven hours of office type applications which simulates what people usually do with their computers such as email, document creation, Web browsing, etc. One hour of high performance applications is included to simulate background virus scan, software update or other periodic high computation needs. The addition of high performance usage in the default configuration also provides visibility in the annual energy costs of the high performance operating power of the system. Defaults and used values are summarized in Table 5-8.

Table 5-8: Summary of Dell's calculator tool default value and used values

Parameters	Default Values	Used Values
Hours per Day running Office Applications	7	10
Hours per day running high performance applications	1	1
Number of work days per year	250	300
CO_2 intensity (kg-CO_2/kWh)	0.72	0.72

We have noted that there seems to be a trend of higher usage by consumers. In fact, many students now never turn their computers off. This behavior should actually increase the use phase from Dell's calculator tool default values. Based on this observation, we calculate the use phase based on the "used values" from Table 5-8. Dell does not provide a specific power consumption value per notebook or scenario. An estimated average power consumption of 27.0 W is assumed. The average kg-CO_2/NB is 256.8, for a four years life time. Table 5-9 shows the main used variables to calculate the use phase CO_2 footprint per notebook.

Table 5-9: CO_2 emissions from a four-year use period in the United States

Region	Avg. kg-CO_2/kw-hr	kW (average)	Use (days per year)	Running time (hrs/day)	Total kW-hr in 4 yr period	Total kg CO_2 in 4 yrs.
1	1.05	0.027	300	11	356.4	374.4
2	0.81					290.1
3	0.63					223.1
4	0.39					138.4

Running time includes the equivalent time of running productivity applications and max performance applications. "Productivity applications" refers to typical office work, such as email, document creation or web browsing using standard office type applications. "Max performance" represents the end user running high-end applications, complex scientific calculations, modeling or 3D games that stress the system, causing significant increases in power consumption. There are also three main states for the system: 1) hibernate/off, 2) sleep, and 3) idle. The combination for specific users varies greatly. For the purpose of this analysis, values from Table 5-9 are used.

5.3 Chapter Summary

This chapter describes the methods and assumptions used to calculate and allocate the kg-CO_2 per SC segment. The main method used to segment Dell's notebook supply chain and to allocate for the CO_2 per supply chain steps is "process-sum." The main assumptions and the SC step components are disclosed in order to facilitate the analysis for the reader. Product specifications are disclosed for the same purposes. The next chapter will condense and guide us through the results of this study, from Tier-1 suppliers to use phase.

6. RESULTS AND FINANCIAL IMPACT

The following chapter explains the results of the analysis by supply chain segments. The case being analyzed in this document is for a notebook manufactured in Asia and delivered to a customer in the U.S. The following section, 6.1, will analyze the CO_2 impact for the specified supply chain bounded in Figure 4-1, namely just Dell's direct operations. The purpose of this focus is dual: first to obtain a perspective of how the CO_2 price policy may impact Dell's operations (tier-1, transportation and assembly) and Dell's non-operations, specifically final customer product use. As previously stated, raw material, tier-1 suppliers and disposal phase are not included as part of this analysis due to the lack of data.

6.1 Dell's Notebook CO_2 Footprint

As shown in Figure 6-1, the major component of the CO_2 footprint per notebook is the suppliers' segment, with 51 percent of the total footprint. It is worthwhile to note that the assembly segment per notebook is just around seven percent of the total supply chain CO_2 footprint for this supply chain segmentation. The transportation section is about 42 percent of the total CO_2 footprint.

As noted, Figure 6-1 excludes the raw material extraction, use phase and the end of life. It just shows just the CO_2 footprint from Dell's operations perspective. In other words, it is trying to answer the question of: what supply chain opportunities are within Dell's reach to improve their operational CO_2 footprint? Although the use phase is one of the most significant portions of a CO_2 footprint, it does not affect the company directly from an operational perspective. In other words, Figure 6-1 is a quantitative representation of the bounded SC under study (see Figure 4-1). Conversely, including and optimizing for the use phase may give Dell a competitive advantage and for this reason we will be discussing it further in this chapter. Each sub-section of this chapter will explain the details entailed on each segment presented in Figure 6-1 and Figure 6-2.

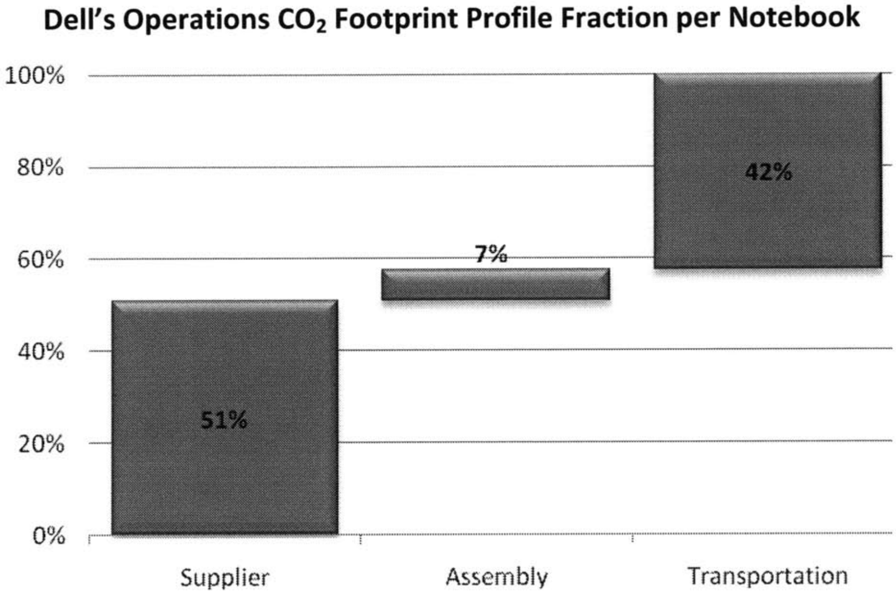

Figure 6-1: Supply Chain CO_2 profile from Dell's operational perspective

Making reference to the previous assumptions and data sets disclosed in Chapter 5 (see section 5.2.2 to 5.2.6) we get a final averaged kg-CO_2 per notebook of 78.8 for the Tier-1 suppliers, final assembly and transportation segments. The transportation fraction showed in Figure 6-1 includes transportation-I and transportation-II. This means that the CO_2 emission (in kg) for the supplier, assembly and transportation segments is 40, 5.4 and 33.4, respectively. These results seem logical. Suppliers include the manufacturing of high-energy intensive materials (i.e. Si, and Al-based). Transportation is across the Pacific Ocean via air mode for all the shipped notebooks to the U.S. (for this analysis). For this study, assembly is responsible for putting all components together into the final notebook product; it is not a manufacturing process.

Figure 6-2, as well as Figure 6-1, shows the supply chain for a notebook assembled in Asia and delivered in the U.S. but this time it includes the use phase. From the calculated Dell's CO_2

footprint, the top three segments (Figure 6-2) are: use phase, suppliers, and transportation-II, with 76.5, 11.9 and 9.7 percent, respectively. The assembly CO_2 is very small fraction of Dell's operation footprint, about two percent.

It is important to notice that the calculation does not include Dell's offices and corporate facilities. As of today, Dell's corporate facilities and offices are carbon neutral, fulfilling its entire energy requirement from renewable energy credits. In case of a CO_2 policy, these facilities will be excluded from the additional cost burden.

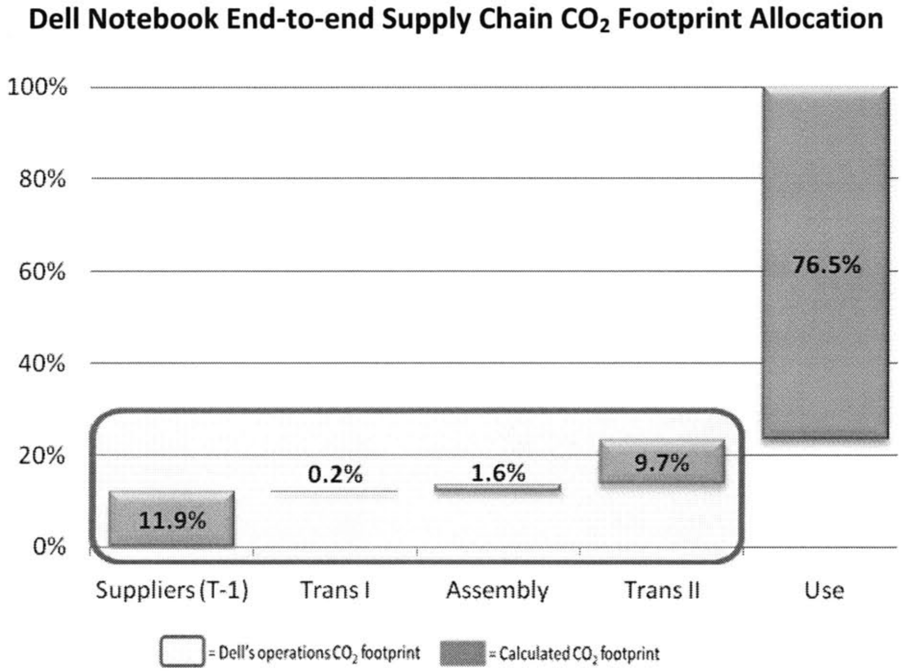

Figure 6-2: Dell notebook end-to-end supply chain CO_2 footprint allocation

At the end of this chapter a set of recommendations will be supplied to Dell in order to mitigate the potential additional costs associated with a possible CO_2 price policy. A sensitivity analysis will also be provided for data validation. The financial impact per notebook will also be calculated. The coming four sub-section will analyze Dell's operations, by fraction of kg-CO_2.

6.1.1 CO_2 Footprint – Suppliers

Only Tier-1 suppliers were used for this LCA due to time and resource constraints for this analysis. These are suppliers from whom Dell directly buys supplies. The information and CO_2 data from these suppliers were gathered from the publicly available Carbon Disclosure Project (CDP) data base. Six tier-one suppliers, 11 percent, account for over 80 percent of suppliers' CO_2 emissions (Figure 6-3). The process to allocate CO_2 per notebook is based on Dell's revenue fraction per supplier. Figure 6-4 shows the process map for suppliers CO_2 allocation. Equation 1 (Chapter 5) shows a supplier's CO_2 allocation example.

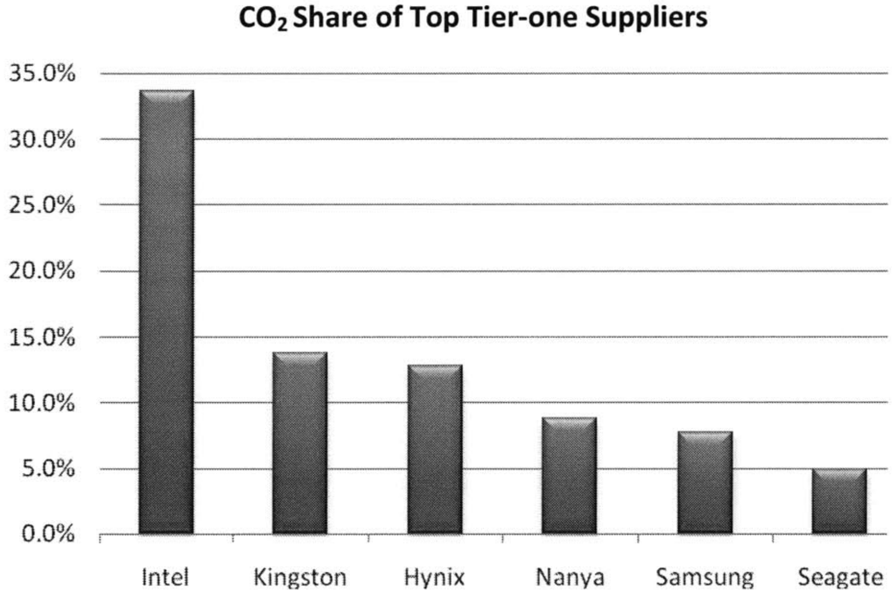

Figure 6-3: Share of top tier-one suppliers accountable for 80 percent of CO_2 emissions

The locations of these suppliers vary, although the majority is located in the Asia region, near the great majority of Dell's notebooks manufacturing facilities. In one way, this helps reduce the transportation CO_2 impact from tier-one suppliers to manufacturing sites, Transportation I. A more detail discussion or the transportation segment will be provided further in this chapter.

After calculating Dell's allocated CO_2 tons the next step was to allocate it per unit basis (per notebook). The following Figure 6-4 shows the framework to allocate the fraction of CO_2 per notebook. Actual data and assumptions are shown in section 5.2.2.

Process Map for Tier-One Suppliers' CO_2 Allocation per Notebook

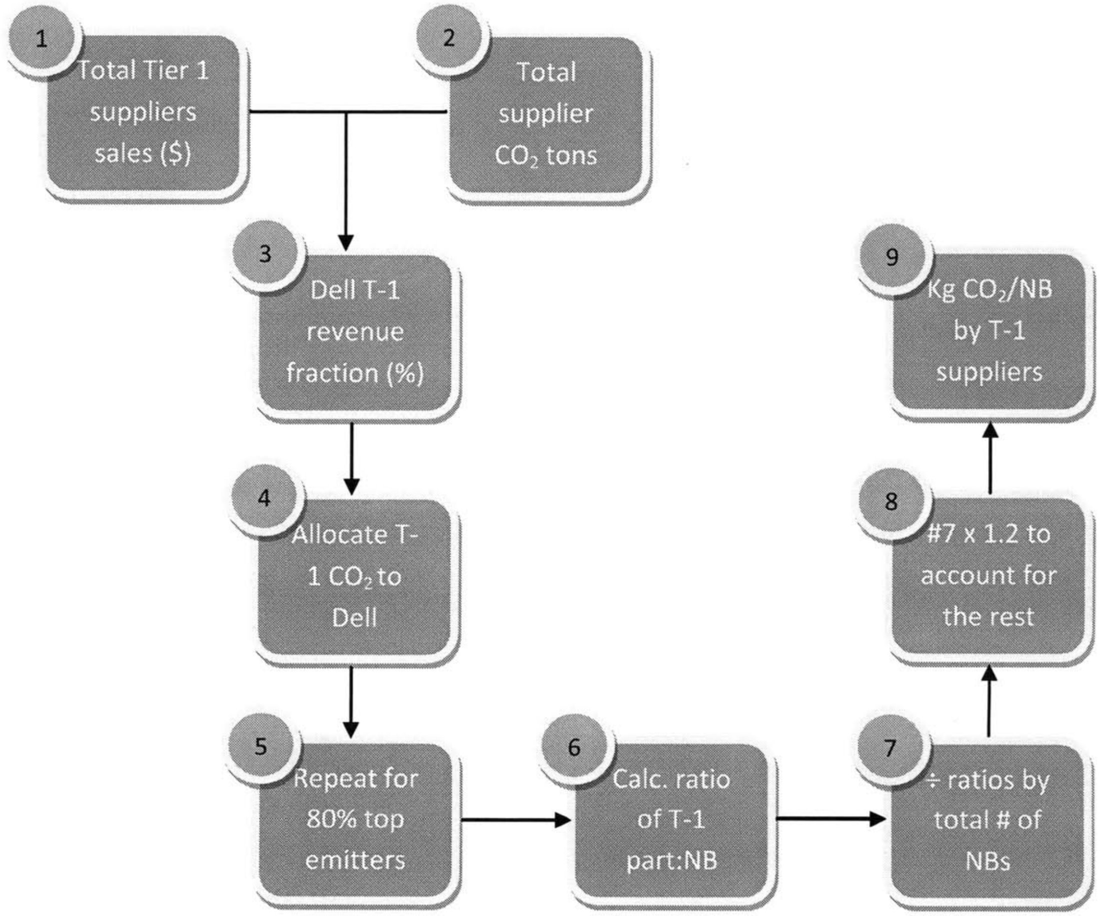

Figure 6-4: Tier-1 supplier's CO_2 allocation framework

One limitation of the current supplier's analysis is the restriction to just Tier-1 supplier data. It is known that before Tier-1 suppliers there is a complex and multiple sources of Tier-2 and Tier-3 suppliers that may account for additional CO_2 allocation per Dell's notebook. The quantity of Tier-2 and 3 suppliers can reach hundreds or thousands, making the calculation and analysis almost impossible to accomplish in the granted period of time for this study. This is one of the current challenges that LCA presents right now. Solving or suggesting options to solve this allocation issue is out of the scope of this study.

6.1.2 CO_2 Footprint – Transportation

As shown in Figure 6-5, transportation is divided into three main segments:

- Transportation I: is the transportation of components from Tier-1 suppliers to Dell/ODMs facilities.
- Transportation II: is the finished good transportation and is divided into two sub-segments.
  - II-A: is the transportation of finished goods from Dell/ODMs facilities to U.S. fulfillment centers.
  - II-B: is the transportation of finish goods from U.S. fulfillment centers to the final customer.

Figure 6-5 shows the fraction of each transportation section. The biggest contributor of the transportation CO_2 segment is Transportation II-A with 96.3 percent.

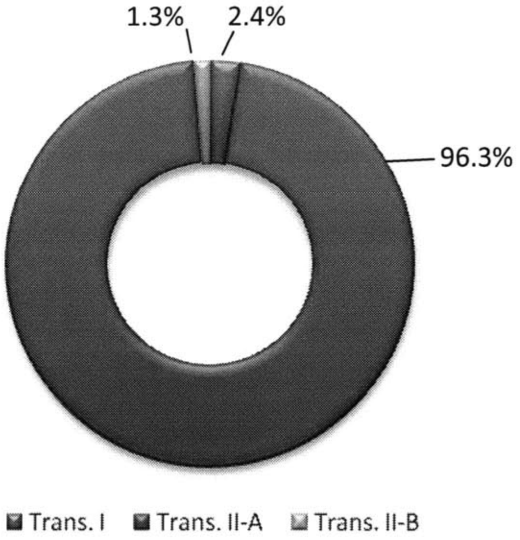

Figure 6-5: Transportation CO_2 contribution by segment

The main reasons for transportation II-A being the greatest contributor is the distance and the transportation mode. Table 6-1 compares the average distances and main transportation modes per transportation segment.

Table 6-1: Dell's notebook supply chain transportation segments comparison

Transportation Segment	Avg. Distance (km)	Main Transp. Mode	CO_2 Intensity ($kg\text{-}CO_2/Ton\text{-}km$)[18]
Transportation I	1,130	Airplane	0.56
Transportation II-A	11,685	Airplane	0.56
Transportation II-B	450	Truck/Rail	0.14

Transportation II-A has the longest average distance and the greatest CO_2 intensity transportation mode, airplanes. This segment of the supply chain is very important and energy intensive. Air flights will start to be included into the EU-ETS from 2012 and U.S. also plans to include this industry by the same time.

6.1.3 CO_2 Footprint – Final Assembly

This segment of the CO_2 footprint is based on ODMs total reported and estimated energy consumption. Most of Dell's notebook final assembly occurs in Asia. For this calculation, only the energy consumption per facilities (kW-hr) is used as CO_2 generator. The average Asia CO_2 intensity equals 0.794 $kg\text{-}CO_2/kW\text{-}hr$[19].

As noted in Figure 6-1, assembly represents around seven percent of Dell's direct operations (suppliers, assembly, and transportation). It is interesting the relatively low fraction of assembly CO_2 footprint from Dell's direct operations and even more appealing from end-to-end supply chain (Figure 6-2) with almost just two percent. It is important to mention that this

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[18] http://www.carbonfund.org/site/pages/carbon_calculators/category/Assumptions

[19] IEA.org

study separates Tier-one suppliers/manufactures of high energy intensive components (Al, Si, etc.) from final assembly of finished goods. The data and allocation process is discussed in Chapter 5.

One of the reasons for the relatively low CO_2 footprint for this supply chain segment is the fragmentation of tier-1 suppliers and final assembly. Many other case studies found in the literature bundle those two segments into one. For differentiation purposes, those two segments are treated separately in this study. If they were bundled, the CO_2 footprint will be around 14 percent for end-to-end supply chain (Figure 6-2).

6.1.4 CO_2 Footprint – Use

As previously mentioned, in case of a CO_2 price policy the use phase will not be incorporated as part of Dell's potential cost burden. In the case of a national carbon price policy, the additional cost burden from the notebook use phase is to be absorbed by the user. On the other hand, it may give Dell a competitive advantage for customers who are the ones paying the electricity bill for their notebooks power consumption. To that end, a study is performed on the potential CO_2 impact of a notebook.

Table 6-2: CO_2 footprint per notebook for a four years use period[20]

Region	avg. kg-CO_2/kw-hr[21]	Avg. power use (kW)	Days per year	Hrs/day	kW-hr per year	Total kg CO_2/yr
U.S.	0.72	0.027	300	11	89.1	**64.2**

As noticed from Table 6-2, for an average notebook with the specified parameters the footprint is around 64.2 kg-CO_2/yr. Normal industry benchmarks use a standard useful life spam of four years per notebook. Using this same benchmark, the total CO_2 footprint for a notebook with

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[20] http://www.dell.com/content/topics/topic.aspx/global/products/landing/en/client-energy-calculator?c=us&l=en

[21] EIA.gov

this (Table 6-2) profile averages 256.8 kg-CO_2. A sensitivity analysis is calculated in the next chapter section.

6.2 Financial Impact

The main scope of this study is to provide Dell with a sense of the potential cost burden in case of a potential CO_2 price policy. Now that the details of the CO_2 footprint calculations are provided, we can go and calculate the potential cost range impact per notebook. Figure 6-6 shows three different scenarios based on two principal factors; price per CO_2-ton and percentage of free allowances (see Definitions in appendix). The prices and percentages have been collected from independent studies and published policy forecasts.[22] It is not within the focus of the work to forecast prices or policy outcomes.

Based on the results (Figure 6-6) the CO_2 cost per notebook may go from \$0.04 to \$0.06 in Phase I (year 2012 to 2020) of the policy implementation. Equation 6 shows how these numbers are calculated. This excludes the use phase; it only includes Dell's operational financial impact (suppliers, assembly, and transportation). There is a high probability that the \$ per CO_2-ton will increase and the percentage of free allowance will decrease as a function of time. In other words, many agencies and experts predict an average of \$15.00/CO_2-ton with a 97 percent of free allowance for the first phase of CO_2 policy implementation.[22] This may represent an average added cost around \$0.04/notebook (see Table 6-9 for sensitivity analysis). In the case of a policy implementation with zero percent of free allowance and \$15.00/CO_2-ton, the additional cost per notebook may go from \$1.06 to \$1.77. It has also been predicted that after 2030 the price per CO_2-ton will increase somewhere between \$30 to \$60 and the percentage of free allowance will decline between 50 to zero percent. This will represent an average cost of about \$1.06 in year 2030 up to \$7.10 in year 2050 per notebook, business as usual. If we assume a \$15/CO_2-ton, we get the following additional cost per notebook:

[22,22] Point Carbon: www.pointcarbon.com

$$\$15/CO_2\text{-ton} = \$0.02/CO_2\text{-kg}$$

Now, with 97% free allowance, the company would only have to pay for 3% of the carbon permits:

$$\$0.02/CO_2\text{-kg} \cdot (1-0.97) \cdot (78.8\ CO_2\text{-kg/NB}) = \$0.05/NB \qquad \text{Eq. (6)}$$

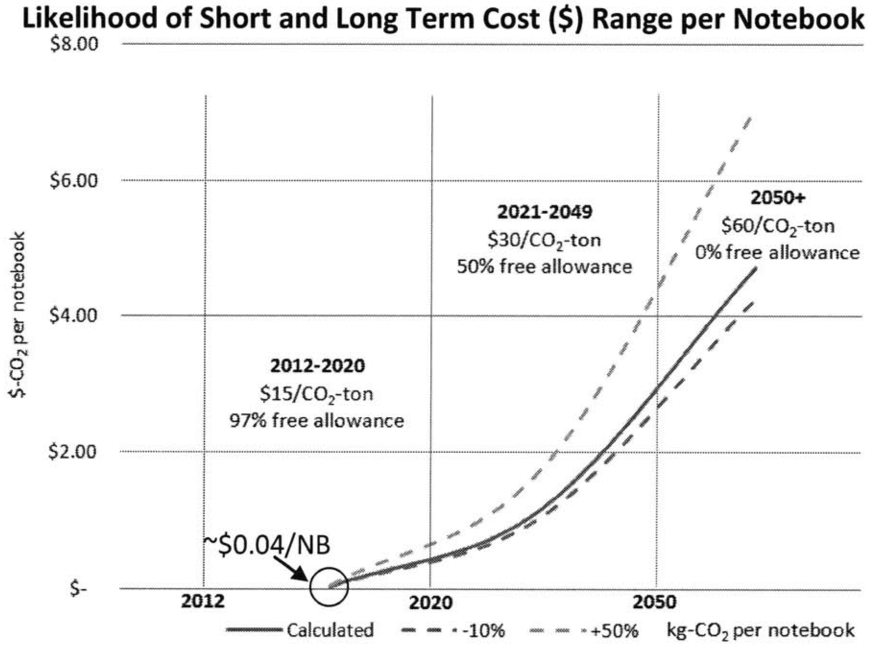

Figure 6-6: CO_2 cost associated per notebook for different price-allowance fraction scenarios

Free allowances are certificate-covered entities (more likely electronic entries) acquired for free that must be surrendered to cover their emissions, typically designated in tons of CO_2 or $CO_{2\text{-e}}$. Figure 6-6 assumes that a gradual price increment and a free-allocation decrease (or allowance auctioning increment) will occur in a consistent way throughout the entire life of the cap-and-trade policy. The assumed variables values (price per ton and percentage of free allowance) are shown in Figure 6-6.

6.3 Sensitivity Analysis

Sensitivity analysis tries to determine the influence of variations in assumptions, methods and data on the results.

Suppliers

The following Table 6-5 shows the variability of CO_2 footprint per suppliers by changes in their percent of reported CO_2 footprint. It will benchmark the actual reported CO_2 data with ± 20 percent variability.

Table 6-3: Sensitivity analysis for Dell's suppliers CO_2 footprint

Scenario	- 20%	Δ (%)	Actual CO_2 contribution	Δ (%)	+ 20%
Figure 6-1	**45.5%**	*-5.5*	51%	*+4.5*	**55.5%**
Figure 6-2	**9.9%**	*-2*	11.9%	*+1*	**12.9%**

From Dell's operational perspective (Figure 6-1) a 20 percent increase in CO_2 per notebook from suppliers will represent four percent increment on their total internal operational footprint. A 20 percent decrease from suppliers will represent approximately six percent drop from their actual suppliers' footprint. We can partially conclude that a relatively large increment (± 20 percent) on supplier's CO_2 (scenario from Figure 6-1) per notebook has relatively small effects on the added Dell's operations CO_2 footprint (average of ±5 percent). Although this sensitivity seems to be very small, any individual or collective effort from suppliers to lower their CO_2 footprint can make a great aggregate contribution; from a financial and environmental perspective. The end-to-end supply chain (Figure 6-2) shows an even lower percentage contribution change after a ± 20 percent suppliers CO_2 change, about ±1.5 percent.

Final Assembly

Table 6-6 examines the sensitivity for the ODM final assembly segment. The only CO_2 source taken into account for this study is the energy consumption per ODM facility. Two main drivers of CO_2 generation and allocation per notebook are; CO_2 intensity (kg-CO_2/kW-hr) and notebook production per unit of time (notebooks/yr). The first one is a function of the kind of energy source use to generate electrical power and the other one is a function of facility capacity, demand and operational efficiency.

Table 6-4: Sensitivity analysis for Dell's final assembly CO_2 footprint

Scenario	Parameters	- 20%	Δ (%)	Actual CO_2 contribution	Δ (%)	+ 20%
Figure 6-1	CO_2 intensity	**5.7%**	*-1.3*	7%	*+1.3*	**8.3%**
	Production Output	**8.5%**	*+1.5*	7%	*-1.2*	**5.8%**
Figure 6-2	CO_2 intensity	**1.2%**	*-0.4*	1.6%	*+0.4*	**2.0%**
	Production Output	**2.0%**	*+0.4*	1.6%	*-0.3*	**1.3%**

As expected, a relatively large change in both parameters causes relative small alters in CO_2 footprint by ODM-final assembly. The two main parameters for calculating the sensitivity of the final assembly CO_2 footprints are analyzed separately (*ceteris paribus*), one at a time. From Dell's operational perspective (Figure 6-1), a ±20 percent change in CO_2 intensity or production output has an average CO_2 final assembly footprint average impact of ±1.28 percent. For the end-to-end supply chain (Figure 6-2), a variability of ±20 percent on CO_2 intensity and production output has an average final assembly CO_2 footprint change of ±0.36 percent.

Transportation

The main modes of transportation used for this analysis are: airplane, truck, and rail. The principal parameter for these transportation modes is energy intensity, kg-CO_2/Ton-km. This is a derivative of the fuel rate of consumption (burn rate) and ton-CO_2/ton-fuel ratio. Most of Dell's CO_2 footprint associate with transportation comes from finished goods transported via airplanes. For this reason, the analysis will be only performed for airplanes. The fuel density equals 0.8 kg/L (EU Commission, 2009). Table 6-7 shows the sensitivity analysis results for this supply chain CO_2 segment. As show in Table 6-7, from a Dell's operational perspective, a change of ±20 percent in fuel burn rate (L/km) or Ton-CO_2/ton-fuel can reduce the CO_2 footprint from two to seven percent or can increase it by three percent, all other things equal.

Table 6-5: Sensitivity analysis for Dell's notebook air transportation-II CO_2 footprint

Scenario	Parameters	- 20%	Δ (%)	Actual CO_2 contribution	Δ (%)	+ 20%
Figure 6-1	Burn rate (L/km)	**35.1%**	*-6.9*	42%	*+3.3*	**45.3%**
	Ton-CO_2/ton-fuel	**35.1%**	*-6.9*	42%	*+3.3*	**45.3%**
Figure 6-2	Burn rate (L/km)	**7.7%**	*-2*	9.7%	*+3*	**12.7%**
	Ton-CO_2/ton-fuel	**7.7%**	*-2*	9.7%	*+3*	**12.7%**

Use

As previously discussed (Figure 6-2) the use phase is the biggest fraction of CO_2 footprint for notebook end-to-end life cycle. It represents around 77 percent of the total footprint, for four years of useful lifetime. This supply chain phase doesn't affect Dell's operations per se, but can be a competitive advantage and a product differentiation if improved for customers. Better energy efficiency can lead to less power consumption, and lower electric utility bills for final users. That said, Table 6-8 shows a sensitivity analysis for CO_2 footprint from notebook usage. For this analysis, ±20 percent will be adjusted to the actual power consumption for a standard notebook configuration (Table 6.4).

Table 6-6: Sensitivity analysis for Dell's notebook use phase

Scenario	Parameter	- 20%	Δ (%)	Actual CO_2 contribution	Δ (%)	+ 20%
Figure 6-2	Power (W)	**72%**	*-5*	77%	*+3*	**80%**

A ±20 percent of variability on the notebook power consumption can lead to an average of ±4 percent on the use phase CO_2 footprint.

6.4 Literature Results Comparison

Several other LCA have been done for desktop computers or specific components of desktop computers (i.e. LCDs, Si chips, memory, HDs, etc.). Even though the author has no knowledge of any available similar study as the one presented in this document, we will try to normalize the available studies and data in order to make a comparison of this study against others. The next sub-section analyses are broken into three main areas: 1) Silicon wafer manufacturing, 2) LCD manufacturing and 3) computer per se.

Silicon Wafer Manufacturing

This section aims to compare the amount of CO_2 footprint reported by some of the six top Tier-1 suppliers (see Table 5-2). For example, (Branham, 2009) analyzed the energy use in microelectronics manufacturing using actual data from Analog Devices located in Cambridge, MA. In their analysis, the total electricity required to build a Si-based device is 270 kWh per six-inch wafer. This includes device fabrication (process and infrastructure) and excludes Si wafer and chemical production. The CO_2 intensity of Massachusetts is 0.523 kg-CO_2/kWh.[23] The calculated CO_2 footprint per six-inch wafer is then 141.2 kg-CO_2. An average laptop (with a mass of 3.59 kg) use approximately 20 grams of Si components (Williams, 2009). A six-inch Si wafer mass approximates 28.3 grams (N. Duque-Ciceri, 2009). The Si wafer energy use can be translated to 9,712 kWh/kg. This gives a total CO_2 footprint per laptop of approximately 101 kg-CO_2. Assuming the average CO_2 intensity (0.469 kg-CO_2/kWh) from Intel's countries of operations (see Table 5.2) we get the following CO_2 footprint per notebook of, 91 kg-CO_2. A 10

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[23] Derived from the following data: http://www.eia.doe.gov/cneaf/electricity/st_profiles/massachusetts.html

kg-CO_2 difference is obtained by varying this assumption. For the purpose of this comparison, the latter result is used.

Other studies (Murphy, 2003) publish results of silicon wafer manufacturing with electricity values of 664 kWh/12-inch-wafer and manufacturing energy requirement and material embodied energy of 1,510 MJ/kg (419 kWh/kg) and 2,900 MJ/kg (806 kWh/kg), respectively.[24] Contrary to Braham's findings, this study includes chemical production and 12-inch Si wafer production. A mass of 127.6 grams is assumed for a 12-inch Si wafer (N. Duque-Ciceri, 2009). The total energy is then 6,429 kWh/kg. A U.S. national CO_2 intensity average of 0.576 kg-CO_2/kWh is assumed. This gives a total CO_2 footprint per notebook of approximately 92 kg-CO_2. This result seems counter-intuitive; a higher CO_2 footprint should be expected because the calculation boundaries for this analysis are wider than Branhan's. On the other hand, there is no mass per 12-inch Si wafer disclosed for this study (Murphy, 2003). We assumed the mass used by Duque-Ciceri (127.6 grams/12-inch Si wafer). Using a 0.469 kg-CO_2/kWh, we get 61 kg-CO_2 per notebook. Now, 18 kg-CO_2 difference is now obtain with just this change in assumptions.

Comparing these results with our available data (Table 5-2) and discussed assumptions, we get a CO_2 footprint per notebook from Si components of 8 kg-CO_2, which is a vast difference from the results found in the literature. A possible reason for this difference is the way the data was calculated. The data we have for this component supplier is on an aggregate basis and is allocated based on revenue fraction, Dell's total volume and market assumptions (we can not disclose those due to confidentiality purposes). For future studies, a direct measure from suppliers' energy usage per component should be done in order to obtain more accurate results.

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[24] 1kWh = 3.6 MJ.

LCD Monitor

An LCD monitor is estimated to require 3,563 MJ/m^2 (R. Kemna, 2005). This only takes into account the display manufacturing process. As previously mentioned, the notebook under study for this project has a 15-inch notebook LCD monitor. The area for such LCD monitor is 0.0692 m^2. The energy requirement is then 247 MJ (68 kWh). Using the average CO_2 intensity from the countries in which Dell's LCD supplier operates (see Table 5-2), 0.72 kg-CO_2/kWh, we get a CO_2 footprint of 49 kg-CO_2 per notebook LCD.

Another study (Ashby, 2009) calculates the average required energy for LCD manufacturing to 3,350 MJ/m^2. Using the same CO_2 intensity (0.72 kg-CO_2/kWh) we obtain a CO_2 footprint of 47 kg-CO_2 per notebook LCD.

Our LCD's available CO_2 data is aggregated among three other notebook components. It was not possible to get segregated data from the supplier. If we assume that the published CO_2 data is equally divided between the four supplier's component (see Table 5-2), then we get monitors total CO_2-ton allocated to Dell, Inc. to be 34,204 tons. If we now assume that the total monitors CO_2 footprint is evenly allocated among all Dell's produced monitors (desktops and laptops) during year 2008, we then get a CO_2 footprint of 0.9 kg-CO_2. Many assumptions and lack of data from our analysis are the main reasons for such disproportioned results. A more detailed disaggregated analysis is proposed for further studies. Also, the methods used to normalize the results of the desktop computer study are not guaranteed to be the most appropriate methods. These methods were used due to lack of data and literature comparison.

Computer Unit

A hybrid LCA analysis was performed (Williams, 2004) for a desktop computer (17-inch CRT monitor) utilizing economic input-output model and sum-process. The analysis includes components manufacturing, transportation and logistics, and use phase for 3 years. William's study concluded a total energy use of 6,400 MJ (1,778 kWh). They assumed global average numbers for this study. For our purpose we will use China's CO_2 intensity of 0.794 kg-CO_2/kWh. Under this assumption the CO_2 footprint for this desktop computer is estimated to 1,412 kg-CO_2. We normalize this result by the computer's weight in order to make it more "apples-to-apples" with our notebook analysis. The assumed weight for this desktop computer is assumed to be 25 kg. Based on this assumption we get a 56 kg-CO_2/kg-computer. Our notebook computer is estimated at 3.59 kg, which based on this calculation should get a CO_2 footprint of 201 kg-CO_2.

Our final results for our analyzed notebook supply chain (4-years of useful life instead of three) we get a total CO_2 footprint of 336 kg-CO_2. For a three-year useful life, we get a total CO_2 footprint of 271 kg-CO_2. To our surprise, the normalized rule that we used (weight based) to correlate between the literature results and our final results seems to be in range between each other, with a 26 percent difference.

6.5 What Would be Needed to Bring Manufacturing Back to the U.S.A.?

The following section examines what is needed (price of CO_2, CO_2 intensity per country, labor wages, and taxes) in order to make manufacturing in the U.S. competitive with China's. Table 6-7 shows the comparison variables for both countries. The analysis is for notebooks customers in the U.S.A.

Table 6-7: Display of key variables for decision making of manufacturing location under carbon policy

Variables	U.S.A	China
CO_2 price (\$/CO_2-ton)	?	?
CO_2 intensity (kg-CO_2/kWh)	0.39[a]	0.79
Energy intensity (kWh/NB)	6.22	6.22
Labor cost per hour per person (\$/hr/per)	21.03	1.24[b]
Labor cost per notebook produced (\$/NB)[c]	5.25	0.31
Air transportation cost (\$/NB)	0.00	3.00[d]
Corporate Tax rate (%)	39.7[e]	25.0[f]
Tax cost per notebook produced (\$/NB)[g]	3.97	2.50
Finished goods air transport footprint (kg-CO_2/NB)	0.0[h]	32.2
Assembly footprint (kg-CO_2/NB)	2.6	5.4
Tier 1 sup. transportation footprint (kg-CO_2/NB)[i]	2.53	0.79
Suppliers footprint (kg-CO_2/NB)[j]	40	40
TOTAL CO_2 per notebook (kg-CO_2/NB)	5.13	38.39

[a] for U.S.A. Region IV average as define in Table 5-6

[b] forecasted from US Labor statistics report accessed on 4/16/2010: http://www.bls.gov/fls/chinareport.pdf

[c] these numbers are calculated as a direct fraction of the labor cost per hour per person and corporate tax margin assuming a same productivity in U.S. and China and same margins. It is assumed that 15 minutes-man of the labor wage goes to the cost of the laptop.

[d] assumed air transportation cost from China to US, per notebook. No need for air transportation when assembled in the US.

[e] Region IV average tax %: Tax Foundation accessed on 4/16/2010: http://www.taxfoundation.org/publications/show/22917.html

[f] from NSW Government web page, accessed on 4/16/2010: http://www.business.nsw.gov.au/aboutnsw/climate/A14_corp_tax_rates.htm

[g] a \$10 markup per notebook is assumed for both countries.

[h] no need for air transportation when assembled in the U.S.A

[i] it is assumed that Tier 1 suppliers stay at their current geographical locations (mostly in Asia) and their shipping method is air instead of ocean.

[j] it is assumed to use the same tier-1 suppliers for both regions. Now we consider the CO_2 footprint without the suppliers (which is the same for both at 40 kg/NB).

The following cost equations are used to calculate the break-even point. This represents the needed price per ton of CO_2 in order to make the assembly of U.S. notebook market in the U.S. competitive, compared to China's.

$$\text{TOTAL COST} = \$\alpha/CO_2\text{-kg}\ (\text{kg-}CO_2/NB_{assembly} + \text{kg-}CO_2/NB_{Trans} + \text{kg-}CO_2/NB_{Supp.}) + \$/NB_{labor} + \$/NB_{tax} + \$/NB_{air\text{-}trans}$$

$$\text{U.S.: TOTAL COST}_{U.S.} = \$/CO_2\text{-kg}\ (2.6 + 2.53) + 5.25 + 3.97$$

$$\text{CHINA: TOTAL COST}_{China} = \$/CO_2\text{-kg}\ (5.4 + 0.79 + 32.2) + 0.31 + 2.50 + 3.00 \qquad \text{Eq. (7)}$$

Then; TOTAL COST$_{U.S.}$ = TOTAL COST$_{China}$

Now solving for $\$/CO_2$-kg, we get;

⇨ $\$/CO_2\text{-kg} = \$0.103/CO_2\text{-kg} = \boxed{\$103/CO_2\text{-ton}}$

In order for the U.S. to be at par with Chinese notebook assembly cost, based on the assumptions and numbers from Table 6-7, the price of CO_2 should be between or above 68 to 114 $\$/CO_2$-ton. This price is almost within the range of what has been proposed as a potential prices of CO_2-ton (anywhere between 15 and 200 $\$/CO_2$-ton). The range is based on the scenario projected in Figure 6-6. The accuracy of the exact numbers needs to be verified and more reliable labor cost and tax data should be used in order to obtain more accurate results. But the purpose of this exercise is to have an idea of the order of magnitude that is needed to shift jobs back to the United States. In many ways this result makes sense under the current assumptions. First, the difference between labor wages is astronomical, around 17X greater in the U.S (Bureau of Labor Statistics, 2010). Second, the tax rate is about 15 points lower in China. But third, there will be no need for air freight finished goods transportation, accounting for 42 percent, around 32.2 kg-CO_2/NB, of Dell's operational CO_2 footprint (see Figure 6-1), if assembly is moved to the U.S.

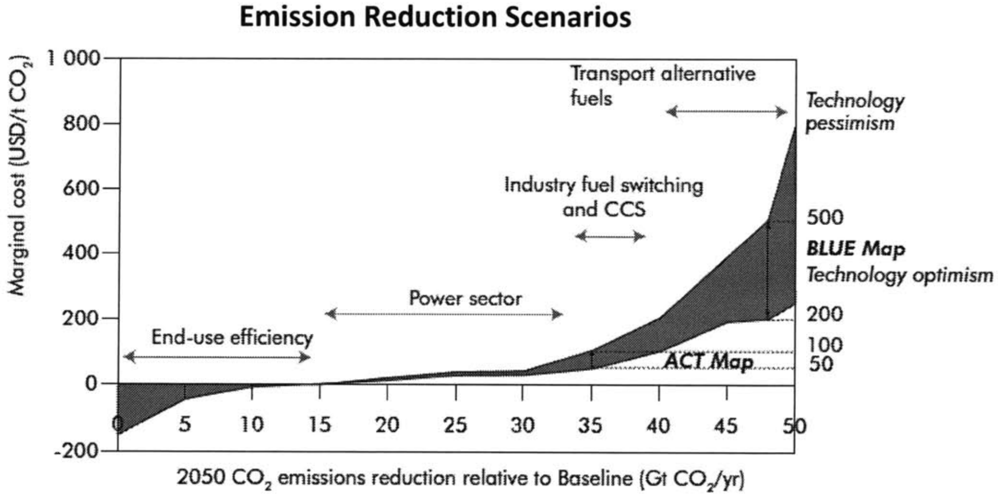

Figure 6-7: Marginal emission reduction costs for the global energy system, 2050

Figure 6-7 shows how the marginal costs of CO_2 abatement in 2050 increase as the targeted CO_2 savings increase beyond those in ACT Map[25] to reach the higher levels needed for BLUE Map. Based on optimistic assumptions about the progress of key technologies, the BLUE Map (IEA, 2008) scenario requires deployment of all technologies involving costs of up to $200 per ton of CO_2 saved when fully commercialized. If the progress of these technologies fails to reach expectations, costs may rise to as much as $500 per ton. At the margin, therefore, the BLUE Map scenario requires technologies at least four times as costly as the most expensive technology options needed for ACT Map. However, the average cost of the technologies needed for BLUE Map is much lower than the marginal, in the range of $38 to $117 per ton of CO_2 saved. This could be enough to shift economical production from China to the U.S.

6.6 Chapter Summary

The estimated added cost for Phase I (year 2012 to 2020) of the cap-and-trade policy implementation may be from $0.04 to $0.06 per notebook, average around $0.04. In the case of a policy implementation with zero percent of free allowance and $15.00/$CO_2$-ton, the additional cost per notebook may go from $1.06 to $1.77. From Dell's operational perspective, the transportation segment accounts for half of its CO_2 footprint. From an end-to-end supply chain LCA, the use phase followed by suppliers and then transportation are the three main CO_2 footprint contributors. A sensitivity analysis was performed on each of the individuals SC-LCA segments to study the variability of relatively high percentages of change in strategically selected parameters. The greatest variability in CO_2 footprint contribution was observed for finished goods air transportation, going from five percent CO_2 reduction to three percent CO_2 increase. A literature comparison is done between several specific components (Si wafers, LCD and desktop). Results for the Si and LCD were very far away from each other, showing no correlation between results. For the desktop-vs-notebook comparison, weight normalization was done and a very similar result was obtained to the actual calculations for this notebook

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[25] Is a scenario analysis of CO_2 abetment cost prepared by EIA

study. In order for the U.S. to be at par with Chinese notebook assembly cost, based on the assumptions and numbers from Table 6-7, the price of CO_2 should be between or above 68 to 114 \$/CO_2-ton.

7. CONCLUSIONS AND RECOMMENDATIONS

From its early days, 25 years ago, Dell has been a leader in supply chain best practices and strategies. The company is now entering into a new business life cycle and must plan accordingly. Many factors are affecting this new life cycle trend; from company maturity to customers behavior to national and international policies. This research is focused on national and international energy and environmental policies. The main purpose of this study is to give the reader a fundamental knowledge of the transition that the company is going through, some case studies about energy policies implemented in other countries and its lessons, and the potential cost burden for Dell in the highly probable scenario of a US CO_2 price policy. More detailed studies are recommended in order to obtain results by product. These results would be easier to compare with publicly available literature.

The case study for this research is for a notebook manufactured in Asia and delivered as a finished good in the US. Based on CO_2 forecasts, scenario shows impact per notebook around: \$0.04/NB from year 2012 to 2020. In the case of a policy implementation with zero percent of free allowance and \$15.00/CO_2-ton, the additional cost per notebook may go from \$1.06 to \$1.77. This cost can go over \$4.70 per notebook by 2050, business as usual. There are several CO_2 contributors across Dell's supply chain. The use phase is the biggest CO_2 contributor from an end-to-end LCA, contributing around 77 percent of the total CO_2 footprint. From Dell's operations perspective, the transportation and suppliers' segment are the greatest contributors with 42 and 51 percent, respectively.

A simplified analysis is done to verify the viability of bringing back notebook assembly to the U.S.A. Under the assumed scenario the price of CO_2 should be between or above 68 to 114 \$/CO_2-ton, average of \$103/CO_2-ton.

There are several risks associated with the potential implementation of a US CO_2 cap-and-trade policy. The main risks are: (1) fraction of free allowances going down, (2) the price of CO_2-ton going up, and (3) the final allocation of CO_2 to Dell from suppliers and distributors. These three main risks can play a great deal in the final added cost per notebook to Dell.

We recommend that Dell systematically track and/or adapt to changes accordingly in the following areas:

- Track high energy intensive manufacturers (chipsets, memory, processors) and Si and Al components in order to design supply chain networks that minimize the cost of high carbon intensive countries.
- Track oil prices and CO_2 additional cost by country and include this potential additional cost in your network design in a country by country basis.
- Design and select your facility locations taking into consideration that air will start charging the CO_2 cost in EU and potentially in the US / Asia by 2012
- Track fraction of free allowance, price of CO_2-ton and allocation of CO_2. This will let the company more precisely forecast the potential cost associated with a cap-and-trade policy implementation.
- Increase notebook power consumption efficiency.

Expanding more on this last point, right now there is no structured incentive to make PCs more efficient from a carbon credit point of view at the national level. The power consumption for this electronic equipment is standardized by DOE/EPA Energy Star Ratings. In other words, the company has to comply with a minimum requirement of power consumption. This standard is tightening periodically. If the company decides to go beyond the minimum Energy Star requirement they may have a competitive advantage over other PC brands, only if they can capitalize on it and get the minimum required ROI from such investment.

As of today, there is no national legislation for encouraging OEMs to make their equipment more energy efficient, but there are some examples of fragmented initiatives at the state, private, and federal level. For example, California adopted a "first in the nation" mandate to reduce electricity demand that requires TVs to be more energy efficient. Some other efforts are being made through the EPA/DOE Energy Star and some other initiatives by professional associations like NEMA. Another example is the CAFE standards in the automobile industry. Right now the only encouragement that can be associated to a potential energy efficiency mandate is under the current US Senate Kerry-Boxer bill under Title II – Section 202: State and Local Investment in the Energy Efficiency and Renewable Energy. This bill (or an updated version) will be brought to the Senate floor for debate in late April 2010. Additional to this the US-EPA plans to have the first GHG emission regulations by mid 2010. Because of these initiatives and the potential of national legislations in the energy efficient sector, Dell must be prepared to know the specific places, within their supply chain and its products, where they can take a competitive advantage in their industry.

APPENDIX I

Definitions:

Allowance: Certificates (more likely electronic entries) covered entities acquire and must surrender to cover their emissions, typically designated in tons of CO_2 or CO_2-e.

Auctioning of allowances: In a cap-and-trade system, specifying that the allowances would be auctioned off to the highest bidders and the revenue from the auction collected by the public agency responsible for the system.

CO_2 tax: a tax per unit of CO_2 or CO_2-e whose level is set by a public entity, requiring covered entities to pay the tax for every ton of CO_2 emitted. The desire to avoid paying the tax provides an economic incentive to reduce emissions.

Covered entity: Used here to refer to organizations or individuals who are covered by a cap-and-trade system (or CO_2 tax) and therefore must surrender allowances or pay the tax to cover emissions for which they are deemed responsible.

Credits: If allowed under a cap-and-trade system, these are certificates that can be used in place of allowances. They are generated from activities of entities not covered by the cap-and-trade system. Entities hoping to sell into the system would need to have credits approved and certified on the project-by-project basis by the public entity overseeing the crediting activity. Approval and certification is meant to assure that the number of credits granted is consistent with the requirements spelled out in the policy. Usually this meant that the entities reduced emissions from a baseline (that must be established and approved) by the amount of the credits they are claiming.

International linkage: Allowing a domestic cap-and-trade system to be linked to a cap-and-trade system in another country, requiring that each country honor the allowances issued by the other.

Safety valve: A Feature of a cap-and-trade system where the public entity managing the system announces a maximum price for allowances, and stands ready to sell as many additional allowances beyond the cap level that entities are willing to purchase at the set price.

Upstream and downstream regulation: The point in the fuel production, refining, conversion, distribution, and combustion chain where emissions are regulated. Downstream refers to regulation of the final fuel users who burn the fuel and release the emissions. Upstream refers to fossil fuel producers (importers) deemed responsible for emissions equal to the carbon content of the fuel sold. There are possibilities of midstream regulation as well, for example, gasoline retailers, petroleum refiners, or natural gas utilities could be required to surrender allowances (or pay a CO_2 tax) for the carbon content of the fuel they sold.

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