Impact analysis of packaging box composition on supply chain emissions

(A case study with Dell Technologies)

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ABSTRACT

This capstone project studies the methods to effectively calculate scope 3 emissions for the packaging boxes of Dell Technologies. The study emphasizes that all sustainability elements are interconnected, and trade-offs need to be considered to optimize overall sustainability in packaging. The model answers questions such as the relationship between material composition, and greenhouse gas emissions, how it can help teams make better decisions, and how greenhouse gas emissions can be controlled by changing packaging variables such as recycled content. The study also presents dashboards that calculate and analyze the total emissions under scope 3, category 1, and category 4 for different packaging types shared by Dell Technologies. The dashboard requires two inputs: a split of air vs. ocean mode of transportation and the packaging type. Our results show that weight, distance traveled, and material type are major factors contributing to emissions. Category 1 is affected by the weight and type of material, while Category 4 is affected by the weight and distance traveled. The study also suggests that Dell Technologies' control over category 1 emissions is limited by the nature of the supply chain, and changing material or suppliers for corrugated boxes is the only direct influence they have. The project presents insights into which component of the packaging generates the maximum emissions, how recycled content impacts emissions and the variation in emission factors by region. Ultimately, this project can help Dell scale this exercise across multiple use cases to achieve their sustainability goals.

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1. INTRODUCTION

1.1 MOTIVATION

Consumer-facing companies have set ambitious targets for zero or significant reductions in greenhouse gas emissions to improve corporate sustainability performance. Sustainable packaging is one of the key elements to achieving those goals. Packaging efforts mainly focus on improving circularity, reducing greenhouse gas emissions, or a combination of the two. (Feber, Gao, & Hundertmark, 2021). An important fact, which is not always well understood by consumers, companies, and other stakeholders, is that the lowest-carbon material does not always have the highest recyclability or use of recycled content.

This trade-off between reduction of greenhouse gas emissions and using recyclable materials for packaging requires a decision as to which aspects of packaging get prioritized in terms of sustainability. Most of a company's focus on packaging is on improving recyclability and increasing recycled content (Rivera, 2021). However, to understand the greenhouse gas emissions from packaging, we believe it is important to take an end-to-end view of the supply chain and logistics of the packaging composition materials and apply a science-based approach to quantifying emissions profiles.

1.2 SPONSORING COMPANY: DELL TECHNOLOGIES

DELL has announced its commitment to sustainability and reducing its environmental impact. The company has pledged to recycle or repurpose an equivalent product for every item purchased by a customer. This initiative aims to reduce waste and promote the circular economy. In addition, DELL plans to use recycled or renewable materials for over 50% of its product content and 100% of its packaging. This goal will help reduce the company's carbon footprint and decrease its reliance on non-renewable resources.

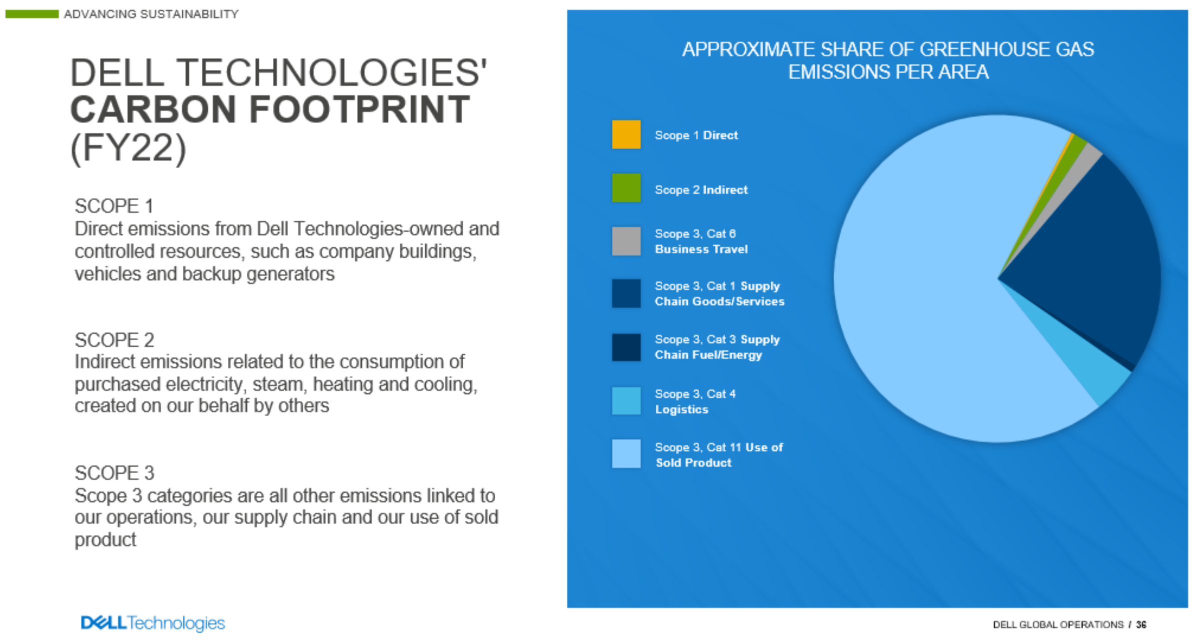
Another key objective for DELL is to reduce its Scopes 1 and 2 greenhouse gas emissions by 50% by 2030. Figure 1.2.1 shows its current greenhouse gas emissions around all different scopes. The company plans to achieve this by implementing various measures such as investing in renewable energy and increasing energy efficiency across its operations.

DELL recognizes the importance of working with its direct material suppliers to achieve its sustainability goals. The company plans to partner with its suppliers to reduce greenhouse gas emissions by 60% per unit of revenue by 2030. This will require collaboration and commitment from all parties involved, but it will ultimately result in a more sustainable supply chain and a positive impact on the environment.

Dell has established environmental sustainability targets (Motes, 2021) concerning greenhouse gas emissions and recycled product content. To achieve 100% recycled packaging material content, Dell is developing new different types of packaging: individual (Tier 1,2,3) and multi-pack packages. This raises the question: How the change in packaging composition affects the logistics costs and greenhouse gas emissions?

Figure 1.2.1

Overview of Dell Technologies Carbon Footprint (FY2022)



Note. Role of supply chain in environmental impact assessment. DELL MIT Capstone presentation. Copyright 2022 by Dell Technologies.

1.3 PROBLEM STATEMENT AND RESEARCH QUESTIONS

To support the Dell packaging team to reduce carbon emissions and cost decisions as they move toward achieving their recycled content goals, this capstone project provides a quantitative dynamic model to define the relationship among recycled packaging material composition, emissions, and cost.

It is important to recognize that the mode of transportation and the recycled content used in the material are interlinked and that there are some important trade-offs to consider when thinking about how to optimize overall sustainability in packaging. In this context, the questions answered include:

1. What type of relationship exists in the material composition of the packaging, cost, and greenhouse gas emission?

2. How can the proposed model help teams in making better decisions involving sustainability targets?

3. How greenhouse gas emissions can be modified by changing parameters of packaging composition such as recyclability?

4. How can Dell scale this exercise across multiple use cases?

The study in this project presented a direct relation of weight of the packaging box and distance travelled by it in the transportation during its life cycle, on the total scope 3 emissions. It also establishes the recycled content impact on the Carbon emissions. Dell can extend this study to apply to other packaging boxes to quantify its scope 3 emissions.

2. STATE OF THE ART

The aim of the capstone is to build a quantitative trade-off model showing several scenarios of packaging composition and associated greenhouse gas emissions (also known as carbon emissions/footprint). To achieve the result, we require to establish a relationship between packaging composition and carbon footprint. To understand the dynamics of such relationships, we explored the literature on the relevant concepts: life cycle assessment and carbon footprint calculations.

A lot of research has been done to understand the effective ways of quantifying carbon footprint (greenhouse gas emissions) associated with any or all activity in the lifecycle of any physical material. Under carbon footprint, we further read articles and bodies of literature on methods to identify and calculate the emission factors quantifying these emissions. These concepts were applied to quantify the upstream and downstream processes at Dell.

2.1. LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) draws its analogy from pathology where a disorder is studied by analyzing the life cycle of the pathogen. (McLeod, 1999). Life cycle is defined by identifying the activities during the entire life of the product – from the earth and back to the earth. The next step is to ascertain the resources and energy consumed and the waste generated at each stage. A consolidated evaluation of these data points helps quantify the impact of the product on the environment during its life. (Lee, 2005) With the help of LCA, any organization can isolate their area of scope from the entire life cycle of the product/service and work on mitigating the emissions associated with it. These areas of scope can be further broken down into hot spots, meaning the stages that add the most emissions, and the organizations can work to minimize their impact.

History of Life Cycle Assessment

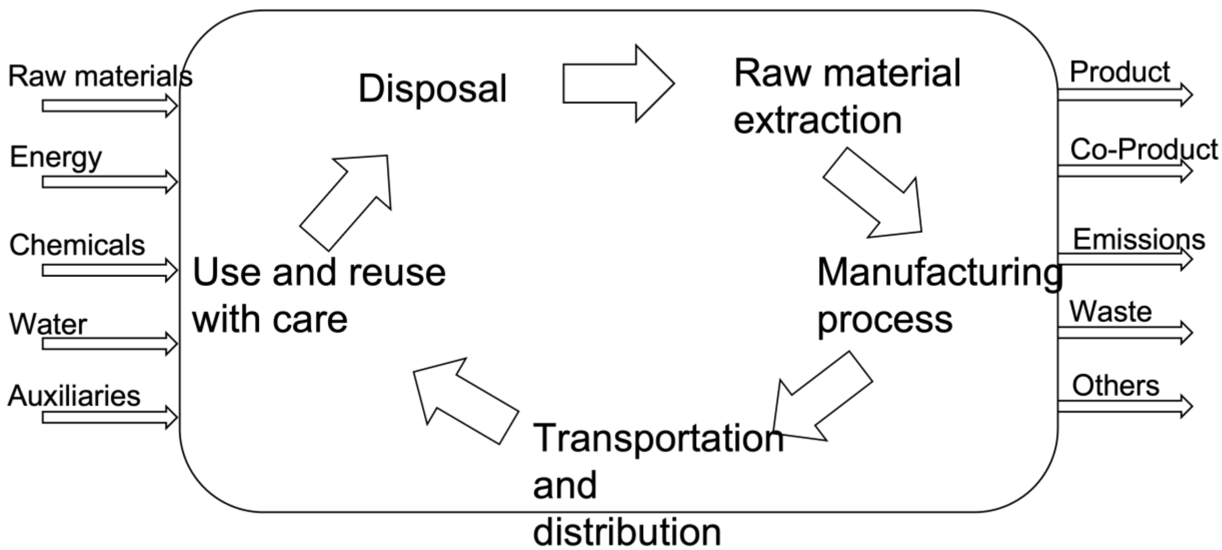
Early in 1960, LCA focused on energy efficiency and raw material consumption. Waste generation was the lowest priority. Then in 1969 the Coca Cola company used the LCA approach to find out the waste generation and environmental impact of their different beverage containers. Also, by the early 1980s environmental concerns gained prominence and other organizations started emphasizing the environmental impact assessment.(Muthu, 2020)

Principle of Life Cycle Assessment

International Standard Organization defines LCA as ‘compilation and evaluation of the inputs, outputs and the environmental impact of a product system throughout its life cycle’. (ISO 14040, 2006). The LCA in simple terms has following steps that help in analyzing the different stages (as depicted in the figure 2.1): raw material extraction, manufacturing processes, transportation, distribution, use and disposal (Muthu, 2020).

Figure 2.1

Several Stages in the Life Cycle of a product/service



Note. Basic concept of LCA. Adapted from *Assessing the Environmental Impact of Textiles and the Clothing Supply Chain* (Second Edition, p. 107), by S. Muthu, 2020, Woodhead Publishing. Copyright 2020 by Elsevier Ltd.

<u>Limitations of LCA</u>

Despite several advantages, LCA approach is very complex and time consuming. The focus of the LCA is majorly on the industrial activities and not on the social and economic aspect. (Lee & Xu, 2005)

In our project, we only focused on the supply chain activities associated with the packaging and mapped these activities to the carbon footprint which is being discussed in the next segment.

2.2. CARBON FOOTPRINT MAPPING

According to World Health Organization, "a *carbon footprint is a measure of the impact your activities have on the amount of carbon dioxide (CO_2) produced through the burning of fossil fuels and is expressed as a weight of CO_2 emissions produced in tons."* (WHO, 2020)

Next, we review the literature which helped us define the area of scope that covers the emissions specific to our project. We researched the following standards and methodologies:

(1) Standards to calculate carbon footprint Scope 3: Category 1 and Category 4.

(2) Methodology to calculate the carbon footprint and

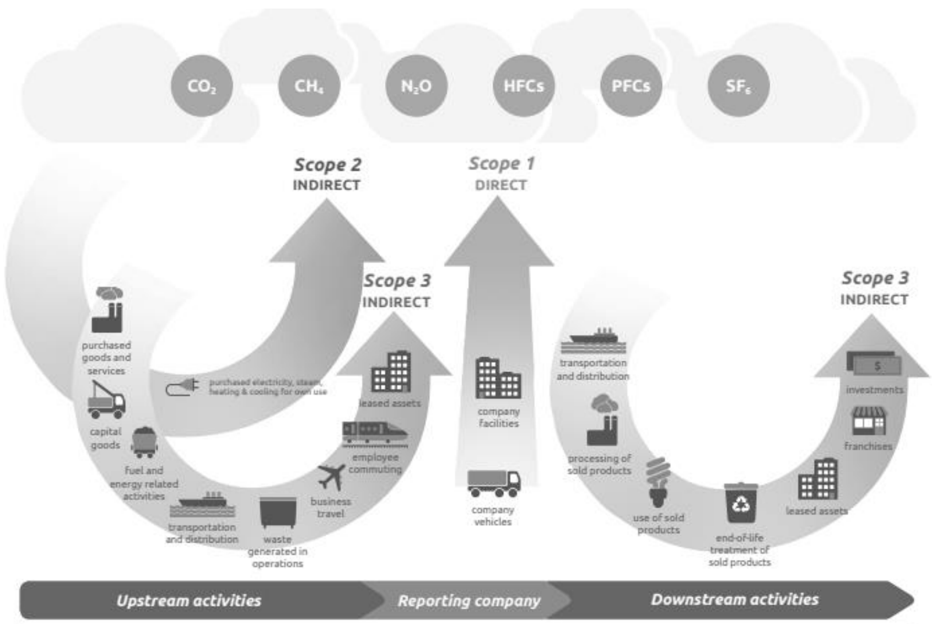
(3) Methodology to incorporate Recyclable Materials Composition into our carbon footprint and cost calculations. (Knapsack problem and Optimization).

Corporate Value Chain (Scope 3) Standard

It is common practice to count, inventory, track and report an organization's carbon footprint (also referred as Greenhouse gas emissions or GHG) by categorizing CO_2 as Scope 1, Scope 2, or Scope 3. GHG emission "scopes" are used by the Greenhouse Gas Protocol, the only internationally accepted standard for companies to account for these types of value chain emissions. (Greenhouse Gas Protocol, 2011)

Figure 2.2

Overview of GHG Protocol scopes and emissions across the value chain

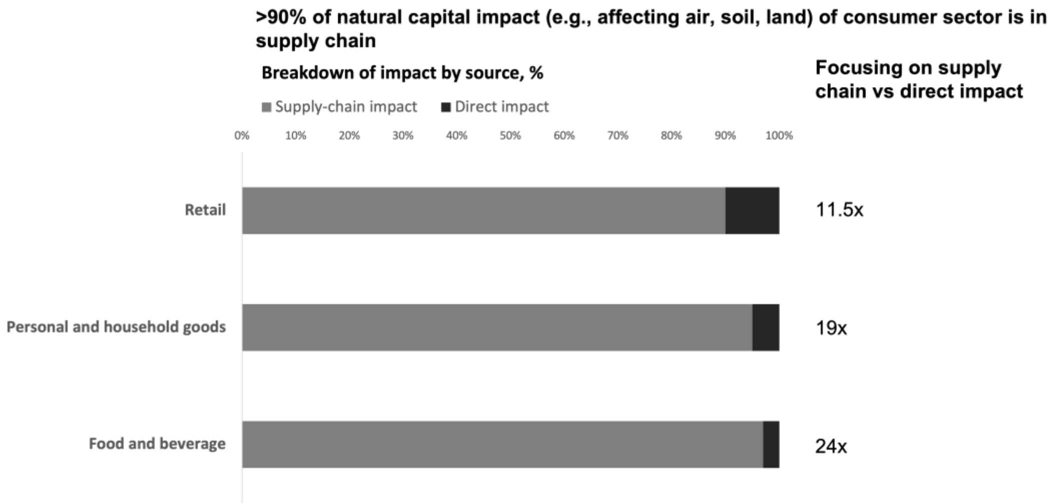


Note. GHG Protocol scopes and emissions across the value chain. From the Corporate Value Chain (Scope 3) Accounting and Reporting Standard, by Greenhouse Gas Protocol, 2011, (https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard-EReader_041613_0.pdf). Copyright *2011* by World Resources Institute and World Business Council for Sustainable Development.

According to a McKinsey report a company's Scope 3 value chain emissions are, on average, 5 to 25 times higher than its direct Scope 1 and 2 emissions, making Scope 3 GHG measurement a critical priority for organizations taking action to decarbonize, reduce their environmental footprint, de-risk their brand. (Bové A., 2016)

Figure 2.3

Role of supply chain in environmental impact assessment



Note. Role of supply chain in environmental impact assessment. Starting at the source: Sustainability in supply chains, adapted from McKinsey & Company, 2016, (https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/Starting%20at%20the%20source%20sustainability%20in%20the%20supply%20chain/Starting-at-the-source-Sustainability-in-supply-chains.pdf). Adapted from 2016 by McKinsey & Company.

Scope 3 emissions are all a company's "indirect" or value chain emissions. For many companies Scope 3 emission will represent most of the business's carbon footprint. The same is applicable for DELL. According to the data provided by DELL (Dell Inc., 2022) the biggest GHG emissions comes from Scope 3 Category 1 - emissions that occur in the supply chain cycle of purchased products and Category 4 - emissions from the logistics transportation and distribution of products.

Our next section under methodology discusses several different methods that exist for quantifying the carbon footprint under the scope of interest in this capstone project. i.e., Scope 3 emissions.

3. DATA & METHODOLOGY

To quantify the carbon emissions, companies adopt several methods based upon the availability of the data points and objective of the calculations(Turner et al., 2015). This section discusses all those different methods under Scope 3 and then narrows it down the specific methodology adopted in calculating the carbon emissions associated with Dell packaging composition.

3.1. GENERAL METHODOLOGY

Based upon the nature of emissions, scope 3 can be further categorized into several categories(Turner et al., 2015). The relevant categories pertaining to this capstone project are Category 1 and Category 4. We will look at one-by-one the existing methods to calculate the emissions related to these categories of scope 3 emissions.

Upon literature review, we found primarily four methods to calculate Scope 3 Category 1 emissions:

1. Spend-based
2. Activity-based (average data)
3. Supplier-specific or primary source
4. Hybrid (mix of spend, activity, and supplier-specific)

The first method is a spend-based carbon accounting estimate. Spend-based Scope 3 carbon accounting takes the financial value of a purchased good or service and multiplies it by an emission factor – the number of emissions produced per unit or monetary value of the goods – to calculate an estimate of emissions:

Spend ($, €, £) * Emission Factor = Spend-Based Scope 3

There is no universal source of emissions factor. The emissions factors to choose to come from government agencies, academic research, company reports, and third-party standards organizations.

To perform a spend-based emissions calculation we need three data sources: purchases, suppliers, and the corresponding emission factors. This data typically comes from the accounting team. The spend-based method works best if the financial purchasing data is available and most accurate. The method calculates the value or number of units purchased, multiplied by an industry average emissions factor for that product. Since spend-based emissions calculations use industry averages, a spend-based estimate will be less accurate. We might estimate the carbon footprint of a product, but we are not accounting for environmental differences between a product made materials composition.

The second calculation method is an activity-based (average data) carbon accounting estimate. This method is like the spend-based method, but instead of using financial data it relies on material weight data.

Activity Metric * Emission Factor = Activity-Based Scope 3

The third method, the supplier-specific or primary source method, is the most accurate form of Scope 3 carbon accounting. Supplier-specific carbon accounting collects GHG data from each supplier using sustainability surveys and data collection workflows. Since supply chains typically represent most of a company's Scope 3 emissions, direct data on purchased goods and services always provides the most accurate Scope 3 calculation:

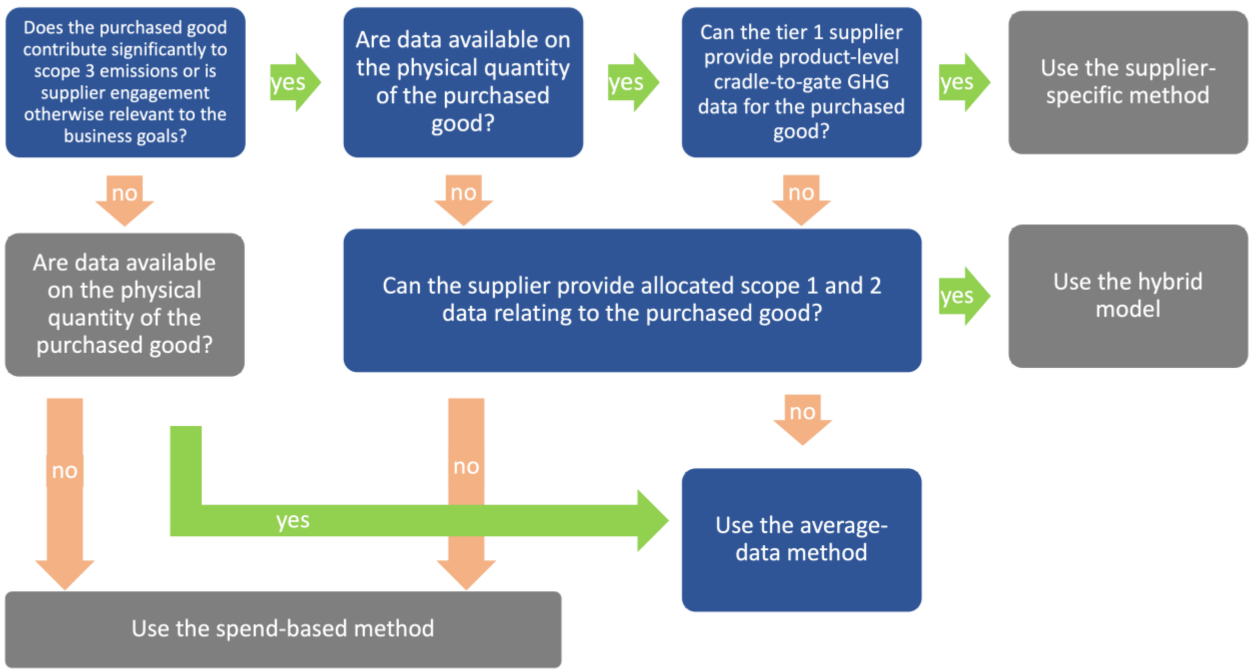
Supplier * Activity * Emission Factor = Supplier Scope 3

Gathering this data can be very time-consuming, and there may be gaps. Some suppliers may not know their emissions data in depth.

The fourth method, a hybrid approach, uses supplier-specific and activity-based data wherever possible, then fills in the gaps with industry averages. This hybrid approach can be more precise than a spend-based or average data-based emissions calculation (Greenhouse Gas Protocol, 2011).

Figure 3.1.1

Decision tree to help companies determine the most appropriate calculation method for estimating category 1 emissions.



Note. Decision tree to determine appropriate calculation method. Technical Guidance for Calculating Scope 3 Emissions, adapted from Greenhouse Gas Protocol, 2011, (https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf). Copyright *2011* by World Resources Institute and World Business Council for Sustainable Development.

Under scope 3 calculation, next relevant category is Category 4 that maps the emissions solely due to transportation and logistics.

To calculate Scope 3 Category 4 emissions from transportation, the following methods are used:

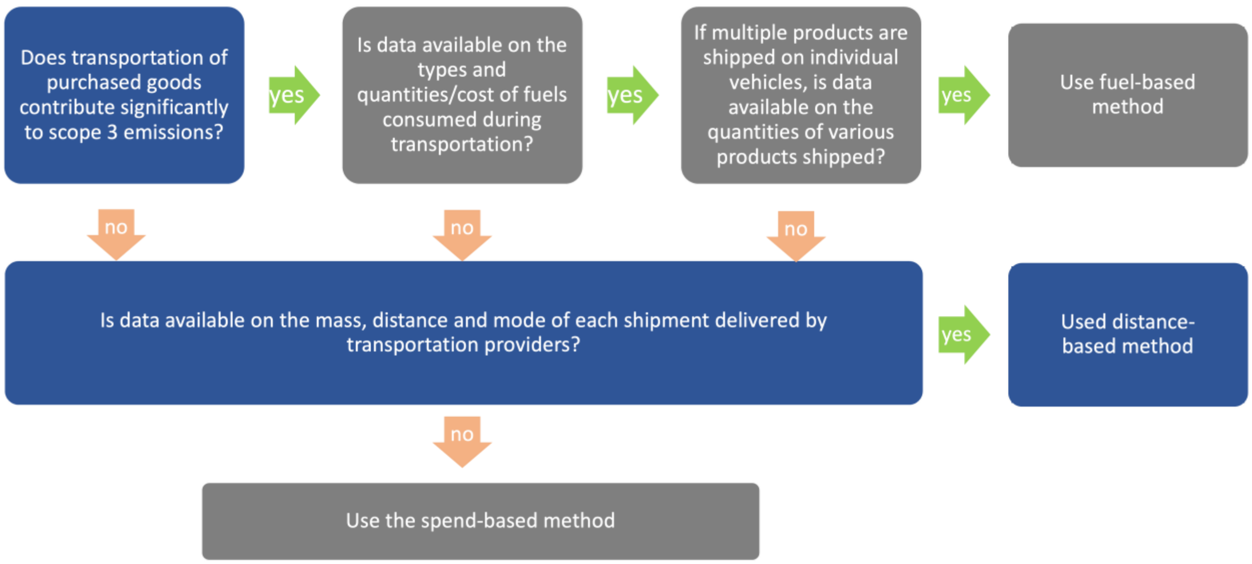
• Fuel-based method, which involves determining the amount of fuel consumed and applying the appropriate emission factor for that fuel

• Distance-based method, which involves determining the mass, distance, and mode of each shipment, then applying the appropriate mass-distance emission factor for the vehicle used

• Spend-based method, which involves determining the amount of money spent on each mode of business travel transport and applying secondary (EEIO) emission factors. (Greenhouse Gas Protocol, 2011)

Figure 3..1.2

Decision tree for selecting a calculation method for emissions from upstream transportation.



Note. Decision tree to determine appropriate calculation method. Technical Guidance for Calculating Scope 3 Emissions, adapted from Greenhouse Gas Protocol, 2011, (https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf). Copyright *2011* by World Resources Institute and World Business Council for Sustainable Development.

After carefully reviewing several methods to calculate the carbon footprint, the next step was to identify the best methodology that helped us in effectively quantifying the carbon emissions due to packaging composition change.

3.2 ADOPTED METHODOLOGY

Our approach was to first define the scope and category for the emission and then to select the most appropriate option to calculate the emissions associated with each stage of the life cycle of packaging boxes. These stages were selected by identifying the relevant supply chain activities associated with the packaging.

Further, we calculated the cost associated with each stage.

Here is a detailed explanation of how we calculated the carbon footprint (Greenhouse Gas Emissions) and cost.

Methodology to calculate the carbon footprint.

Using the decision tree from the GHG protocol, we identified one method to calculate Scope 3 (category 1) CO_2 emissions and one method to calculate Scope 3 (category 4) emissions.

For the category 1 emissions, we used the activity-based (average data) method. In this method, the company collects data on the mass or other relevant units of purchased goods or services and multiplies them by relevant emission factors. Emission factors may be found in the life cycle of a product.

Activity data needed: Mass or number of units of purchased goods or services for a given year (e.g., kg, hours spent). Companies may organize the above data more efficiently by differentiating purchased goods or services into mass and other categories of units (e.g., volume), where appropriate.

Emission factors needed: Cradle-to-gate emission factors of the purchased goods or services per unit of mass or unit of product (e.g., kg CO_2 e/kg or kg CO_2 e/hour spent).

Purchasing records. Data sources for emission factors: Process life cycle databases. (Greenhouse Gas Protocol, 2011).

$$\text{Carbon emissions for purchased goods/services} = \Sigma(\text{value of purhcased goods or service} * \text{emission factor of purhcased good ro service per unit of economic value}(\text{kg CO2e}/\$))$$

For the category 4 emissions, we use the distance-based method (transportation) based on the data set available from the Dell's supply chain team.

In the distance-based method, distance is multiplied by mass or volume of goods transported and relevant emission factors. Emission factors for this method are typically represented in grams or kilograms of carbon dioxide equivalent per ton-kilometer or TEU-kilometer. A ton-kilometer is a unit of measure representing one ton of goods transported over 1 kilometer. A TEU-kilometer is a unit of measure representing one twenty-foot container equivalent of goods transported over 1 kilometer. Distance were provided by the company.

Activity data needed: Mass or volume of the products sold; Actual distances provided by transportation supplier (if actual distance is unavailable, companies may use the shortest theoretical distance); Online maps or calculators; Published port-to-port travel distances.

Emission factors needed: Companies should collect: Emission factor by mode of transport (e.g., rail, air, road) or vehicle types (e.g., articulated lorry, container vessel), expressed in units of greenhouse gas (CO_2, CH_4, N_2O, or CO_2 e) per unit of mass (e.g., ton) or volume (e.g., TEU) travelled (e.g., kilometer). (Greenhouse Gas Protocol, 2011). Dell had provided the emission factors associated with each mode of transportation.

$$\text{Carbon emissions from transporation} \\ = \Sigma(\text{mass of goods purchased}(\text{tonnes or vol }) \\ * \text{distance travelled in transport leg}(\text{km}) \\ * \text{emission factor of transport mode or vehicle} \frac{\text{type}(\text{kgCO2e})}{\text{tonne}} \text{or vol/km}))$$

Using activity-based method for Category 1 emission calculation and distance based method for Category 4 emission calculation, we were able to successfully map the emissions due to the packaging box with the given data set from Dell Technologies.

4. RECYCLED CONTENT & EMISSION

Next step in our project was to evaluate how recycled content in the packaging composition affects the greenhouse gas emission. To understand this relation, let us first understand which category of emission is directly impacted by the selection of material. As mentioned in section 3.2, in the calculation of Scope 3 cat 1 emissions, the emission factor is estimated based on the life cycle assessment for that material.

Under life cycle assessment, it is critical to identify the steps in which the recycled element is introduced in the manufacturing of packaging material. In the packaging material used for the boxes, corrugate material is the heart, and we focused the study for recyclability to this material.

The figure 4.1 shows the life cycle of the corrugate material. It was adopted from the Environmental product declaration (EPD) for the corrugate paperboard boxes.(*The EPD | EPD International*, n.d.). It highlights the stages through which a corrugate box goes through during its entire life cycle.

The recycled content is determined by the percentage of virgin material and secondary material that is fed into corrugator from the upstream raw material stage. Virgin material refers to the material obtained directly from nature (such as cutting of trees, forests) and secondary material refers to the material obtained via the recovery from the waste or the recyclable material.

The manufacturing process of paper begins at a paper mill where either new cellulose fibers or recycled paper are utilized to produce paper reels. These reels are then transported to a corrugator, which consists of a series of machines that combine multiple sheets of paper to form single, double, or triple wall board in a seamless process. The flat board sheets produced by the corrugator are subsequently transformed into corrugated packaging through various converting operations such as printing, die-cutting, folding, and gluing (using tape or stitching)(Sada, n.d.) .

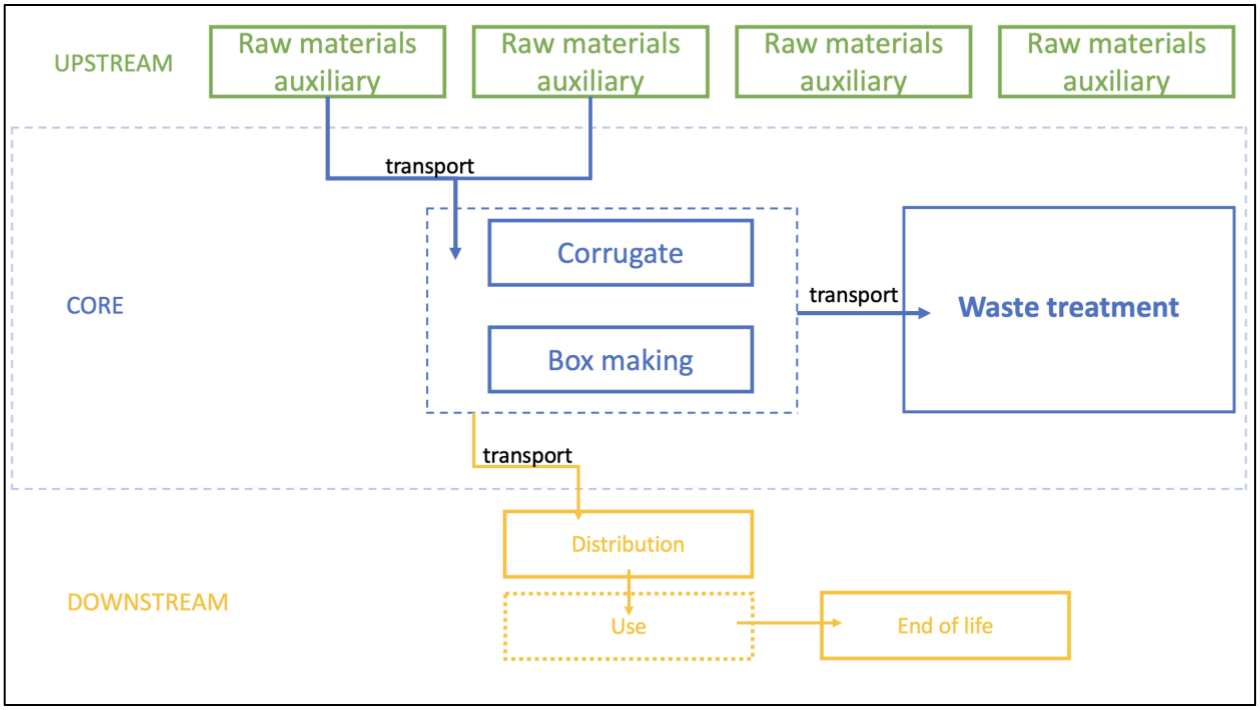


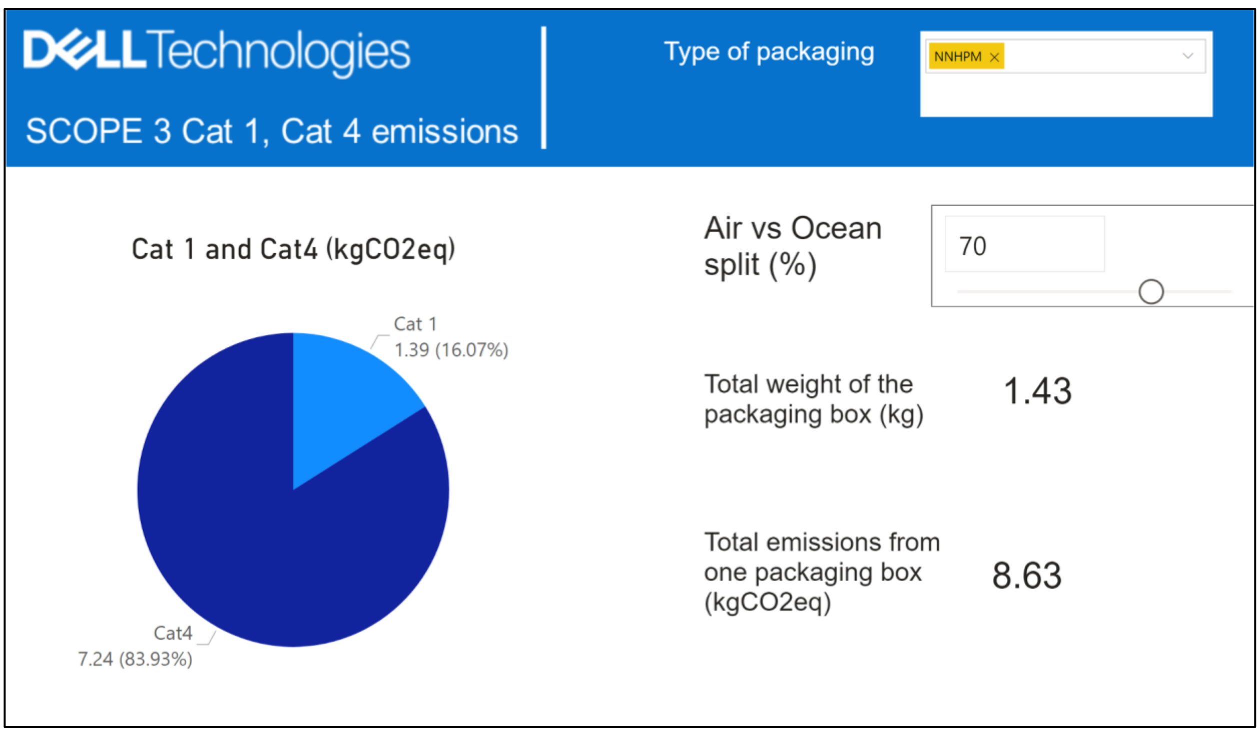
Figure 4.1 Adapted from (*The EPD | EPD International*, n.d.) Boundaries of the Life cycle assessment of the corrugate material.

After identification of the step at which recycled content is affected, we researched to find out the variation of emission factors with change in the recycled content in the corrugate material. i.e., what percentage of raw material fed to corrugator is virgin material or secondary material (Brogaard et al., 2014). These emission factors helped us in quantifying the impact of change in recycled content over the scope 3, category 1 emissions for the packaging material.

5. RESULTS

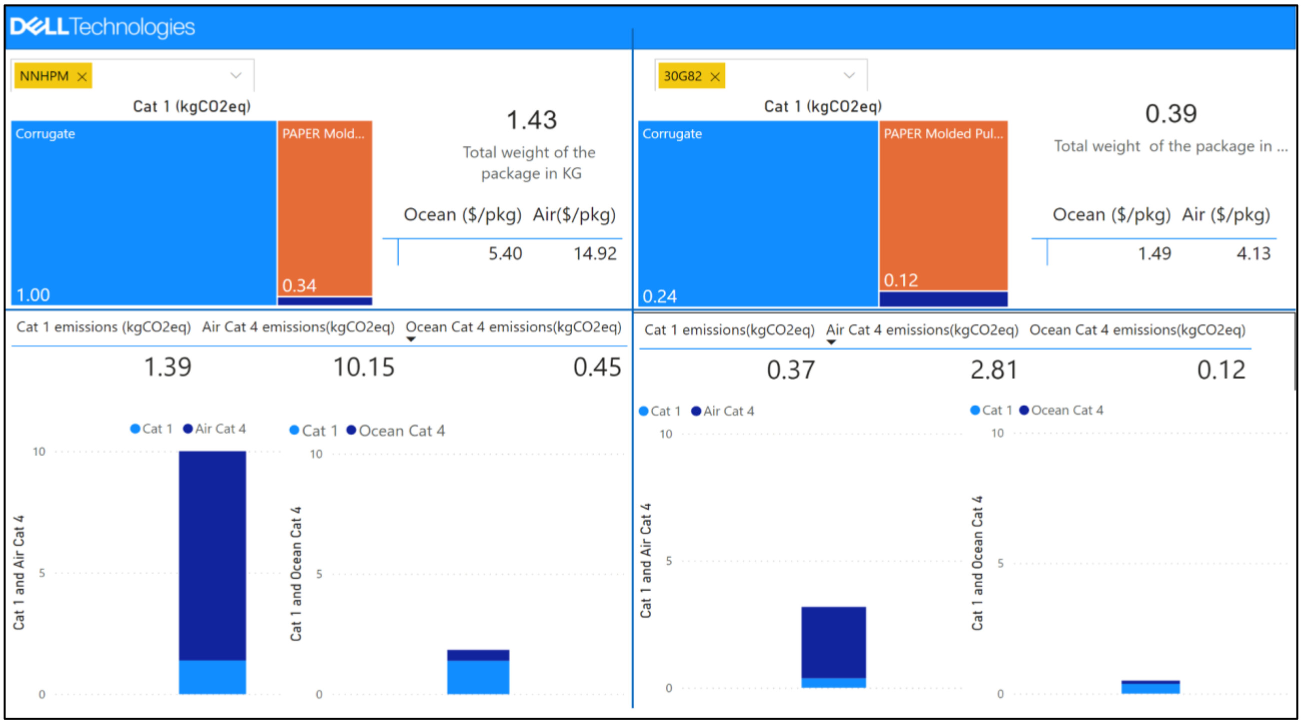
The figure 5.1 shows the dashboard that calculates the total emission under scope 3, category 1, category 4 for any packaging. The dashboard is dynamically embedded with the data points that has necessary values for all the different packaging types shared by the Dell Technologies. This dashboard requires two inputs, one the split of air vs ocean mode of transportation and second the name of packaging. Each packaging has a different composition of material and different weight which is responsible for the variation in the emissions.

Figure 5.1 : Dashboard showing the scope 3 cat 1, cat 4 emission for the selected packaging.



The figure 5.2 shows the second dashboard that we built. It shows at a glance emission by two different packaging. It gives an insight into which component of the packaging is generating the maximum emission and how it is different with the other packaging. It also shows the cost of shipping one unit (upstream and downstream) via ocean vs air mode.

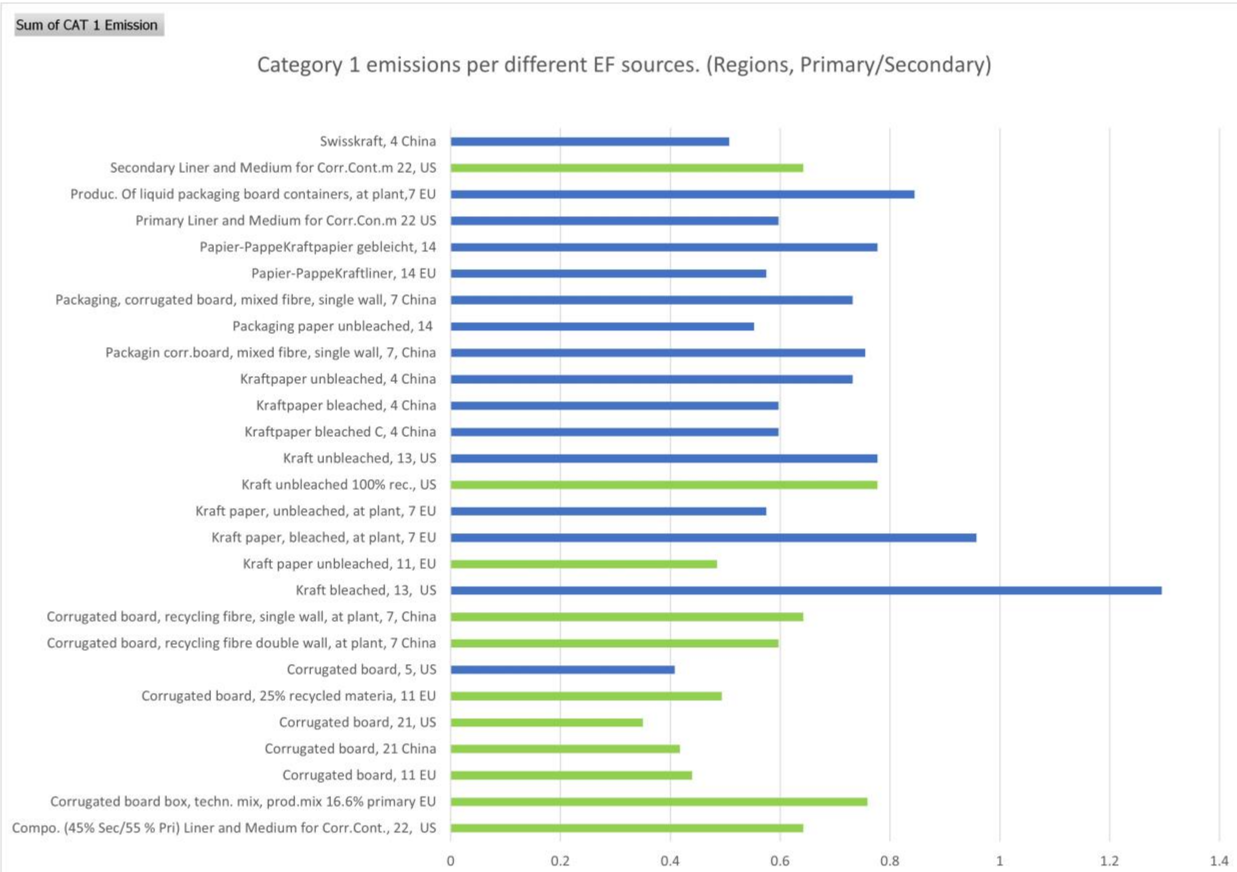
Figure 5.2 : Dashboard showing emissions from two different packaging.



The figure 5.3 shows the plot of emissions due to use of virgin material(primary) vs secondary material. It also shows the variation in the emission factor by region. The emissions produced during the creation of primary corrugated cardboard varied between 0.49 and 2.46 kg CO2-eq/kg of material across 17 datasets, while secondary corrugated cardboard had emissions ranging from 0.31 to 1.26 kg CO2-eq/kg of material across 11 datasets.(Brogaard et al., 2014)

These emissions factor variation with percentage of primary vs secondary material clearly explains the relevance of recycled content in the total emissions. It also highlights other variables such as region and nature of recycling that governs the right emission factor.

Figure 5.3 : Graph showing different emission factors from different region based on the secondary and primary source of raw material.



6. DISCUSSION

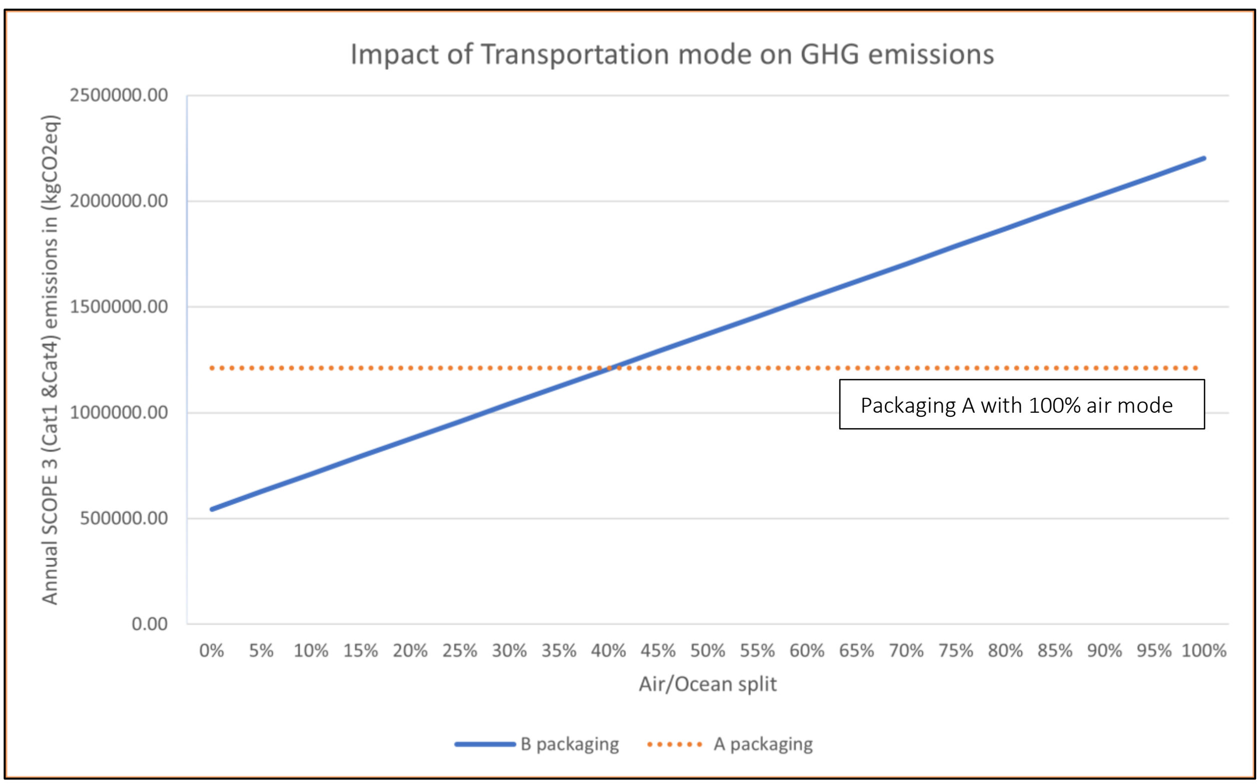
We used the dashboard created in section 5 to study the scenario of two different packaging for the same laptop model over an observed demand of a year. It gives us following two insights –

1) Total emission is 70-80% contributed by the category 4. This means majority of emissions are coming from the supply chain network design and further analysis is required to understand the source of emissions. This can be achieved by using NTM method as described in the section 4.2. Dell Technologies has to capture

the data of the inbound and outbound logistics for the packaging boxes by recording truck/vessel capacity, no. of trucks/vessels employed in the operations, type of trucks/vessels used and how is the supply chain network design. In our case Dell has directly provided the emission factor to calculate this emission. But to further understand and minimize the emission due to transportation and logistics, it is essential to study one level deep to identify the correct source of emission in the current supply chain of the packaging box contributing to category 4.

2) Secondly packaging B has higher emissions than Packaging A due to the higher weight of the packaging B. To bring down the emissions of packaging B, shifting the mode of transport to 42% air vs ocean can bring the emission level at least at par with packaging A. (Figure 5.2.1). Packaging B has a smaller form factor than packaging A. To evaluate the impact of form factor, we require the data to be more granular as explained in point 1.

Figure 5.2.1 : Graph showing impact of transportation mode on GHG emissions



3) Lastly under category 1 emission, recycled content is crucial to decide the emissions level. As seen in the graph figure 5.3, improving recycled content doesn't improve the emissions level always. It depends upon the region and kind of processes used to extract the recycled material and feed it in the manufacturing process. The emission for such step is measured widely via the amount of energy consumed in the process.

From the graph following three points are evident –

1) The recycling process in Europe is the most efficient one as compared to the other continents. This might be ascribed to the stringent environmental laws in play there.

2) Increasing the recycled content (adding more secondary material) doesn't always decrease the emission levels.

3) Dell Technologies control over category 1 emission is limited by the nature of supply chain. It can only control by changing material or the supplier for the corrugate boxes because the processes involved in extraction and pulp making is not directly influenced by the Dell Technologies.

7. CONCLUSION

The research highlights the interconnectedness of various sustainability aspects and emphasizes the need to consider trade-offs to achieve optimal overall sustainability in packaging. While Scope 1 and Scope 2 deals with the direct emissions from the organization, Scope 3 helps us understand the relevance of indirect emissions coming from the material type, supply chain and end use of the material produced by the respective company.

The scope of this project aims to identify the relevant sources for Scope 3 emissions, specifically Category 1 and Category 4. Category 1 maps the cradle to gate emission for the material and Category 4 maps the emissions due to transportation network for the material. This research explores the correlation between material composition and greenhouse gas emissions, demonstrating how it can aid teams in making improved decisions. It also investigates how altering packaging variables, such as increasing recycled content, can help control greenhouse gas emissions.

In this study we were able to identify weight, distance travelled and type of material as major factors contributing to the emission. Cat 1 is affected by weight and type of material (percentage of primary vs secondary material) and cat 4 is affected by the weight and distance travelled by the material.

The study also presents three dashboards to calculate and analyze the total emissions under scope 3, category 1 and 4 for different packaging types used by Dell Technologies. The first dashboard calculates the total emissions for any packaging type, while the second dashboard provides a comparison of emissions and cost of shipping for two different packaging types. The third dashboard shows the emissions produced during the creation of primary and secondary corrugated cardboard, highlighting the variation in emissions factors by region and the importance of recycled content.

The analysis of the data using these dashboards reveals that most emissions are contributed by category 4, which necessitates further analysis using the NTM method to understand the source of emissions. Additionally, the study shows that the weight of packaging significantly affects emissions and highlights the importance of recycled content and efficient recycling processes in reducing emissions. Lastly, it is evident that Dell Technologies can only control emissions in category 1 by changing materials or suppliers for corrugate boxes due to limited control over the extraction and pulp-making processes.

The EFs that were computed in this paper relied on various subjective modeling decisions and methodological presumptions. In addition, this research was essentially constrained by the scarcity and quality of the available data, which mainly came from secondary sources. As a result, these presumptions and constraints give rise to uncertainty and could have had an impact on the findings.

Further research is required in finetuning the Category 4 emissions. This can be achieved by adopting more sophisticated NTM method for calculating the Scope 3, Category 4 emissions. To do so, the company needs to maintain the granularity in its data by capturing the transportation data at the truck/container capacity utilization. In this way more insights can be obtained on how the transportation network should be optimized to minimize the carbon footprint.

However, the study in the given timeframe provides interesting insights into the hotspots of emissions in scope 3. It emphasizes the importance of effective supply chain network design and creates awareness about how actually the process of recycling affects the emission. This can be adopted by other companies looking to define their sustainability matrix and work on reducing their supply chain emissions.

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