Building a Carbon Allocation Methodology across Multiple Business Teams and Activities with Interdependencies

by

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Submitted to the MIT Sloan School of Management and
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Abstract

To prevent the negative effects of climate change, companies around the world are setting and committing to net-zero carbon targets. Achieving this goal comes with operational challenges for companies, e.g., having a standardized method to hold internal business teams accountable for their carbon emission, and empowering individual teams to decarbonize. Especially for large companies with multiple business teams and functions that have interdependencies, allocation of carbon emissions coming from business activities and decisions is complex and not straightforward.

Amazon announced the Climate Pledge in 2019 and committed to achieving net-zero carbon emissions by 2040, by physically decarbonizing its business activities and offsetting residual emissions. Amazon's supply chain is complex, which creates many interdependencies among internal business teams. These business teams often share responsibility over the emissions of single asset or decisions, both internally and externally. This project aims to develop a carbon allocation methodology to allow those business teams to understand their contribution to carbon emission, which will be a source of information for their incremental decarbonization strategies and cross-business collaboration to accelerate physical decarbonization. We will focus on transportation businesses within Amazon and create multiple use cases and allocation logics using available activity data, and then recommend a way to scale the logic to non-transportation businesses, such as buildings, devices, and servers.

This thesis is organized into following chapters;
Chapter 1 Introduction
Chapter 2 Company Background
Chapter 3 Literature Review
Chapter 4 Carbon Allocation Logic
Chapter 5 Research Methodology
Chapter 6 Results and Discussion
Chapter 7 Conclusion and Recommendation

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Note on Amazon.com Proprietary Data

In order to protect sensitive information such as technology, performance, and capability, most data presented in this thesis has been modified or synthesized so that it still conveys the concepts without externalizing information that is confidential to Amazon.com, Inc.

Quantitative data, including numeric values and models as well as data labels and units as presented in tables and charts, have been either redacted, normalized, or adopted referencing existing literature; qualitative descriptions of Amazon technologies, processes, and operations have been generalized or abstracted to what is already in the public domain. This does not change the conclusion of this thesis. Any opinions expressed in this thesis are solely those of the author.

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Acronyms

AWS Amazon Web Services

CARS GHG Protocol Corporate Accounting and Reporting Standards

CDP Carbon Disclosure Project

CI Carbon intensity

CLD Causal loop diagram

COP21 21^{st} Conference of the Parties

DC Distribution Center

EEIO Environmental Extended Input-Output

FC Fulfillment Center

gCO2eq gram of carbon dioxide equivalent

GHG Greenhouse gas

GMS Gross Merchandise Sales

IPCC the Intergovernmental Panel on Climate Change

KPI Key Performance Index

LM Last Mile

LPs Leadership Principles

MM Middle Mile

SBTi Science Based Target initiative

SC Sorting Center

UN United Nations

WBCSD World Business Council for Sustainable Development

WRI World Resources Institute

WWF World Wide Fund for Nature

Chapter 1: Introduction

This chapter provides the background and motivation for building a carbon allocation methodology at Amazon's transportation team. We conclude this chapter by defining the problem statement and the goal for this project.

1.1 Global Climate Change

Since the Industrial Revolution, human activities have contributed to large amounts of greenhouse gases (GHG) emission, the key contributor to global climate change[1]. Although there are natural processes that also contribute to warming of earth's climate (e.g., sun's energy, volcanic eruptions), studies point out that climate change in the past century cannot be caused by natural processes alone[1].

According to a recent report by IPCC, GHG emissions from human activities have contributed to approximately 1.1^{o}C increase in global temperature since pre-industrial period (1850-1900), and in the next 20 years, the global temperature is expected to reach or exceed 1.5^{o}C of warming[2]. The consequences of this 1.5^{o}C warming in the next 20 years are dire; reduced water supplies, reduced agricultural yields, increase in health risk due to extreme heat waves, to name a few[3]. Climate change also poses economic risk; a McKinsey report warned that regions with extreme heat stress will lose annual outdoor working hours in agriculture, construction, and mining, which is equivalent to $4 trillion to $6 trillion in global GDP at risk annually[4].

1.2 Commitments and Challenges to Tackling Climate Change

In order to fight climate change, countries and industries around the world have been taking action and committing to sustainability goals to prevent further global warming. In 2015, 196 countries that attended the COP 21 in Paris signed the Paris Agreement, a legally binding international treaty on climate change that aims to limit global warming to below 2.0^{o}C (preferably 1.5^{o}C) compared to pre-industrial levels[5]. In the same year, United Nations Department of Economic and Social Affairs adopted the Sustainable Development Goals (SDGs), which comprises of 17 actionable goals for countries and businesses to take, including clean water and sanitation (goal 6), responsible consumption and production (goal 12), and climate action (goal 13).

To tackle climate change at a corporate level, each company needs to take measurable actions to reach its sustainability goals. First important step is to measure and report the company's overall carbon footprint emitted from its business operation. Science Based Targets initiative (SBTi), a partnership between CDP, UN Global Compact, WRI, and WWF, created the world's first Net-Zero Standard to guide companies with net-zero carbon targets in line with climate science[6]. As of today, there are 2466 companies worldwide that are committed to SBTi's net-zero carbon transition and are setting carbon emission reduction targets. In addition, more than 9 out of 10 Fortune 500 companies use the Greenhouse Gas Protocol (GHG Protocol) as carbon accounting guideline to report their annual carbon emission to CDP. Detailed summary of GHG Protocol will be explained in Chapter 3.

After measuring the overall carbon footprint at company-level, companies also need to allocate that carbon footprint to internal business teams that contributed to it. This second step is important, especially for large companies with multiple business teams. By allocating carbon footprint at business team-level, each business team will be held accountable for its carbon emission and will be encouraged to take action to decarbonize.

There are organizational challenges to achieving decarbonization goals as a company that has multiple business teams with different functions and operational activities. First, it needs to have a standardized method to measure carbon footprint for different functions. It also needs to have a standardized method to allocate carbon footprint to business teams with interdependencies. Next, the company needs to make sure its business teams have necessary (and good quality) data for measuring and allocating carbon footprint. Finally, the company needs to find a way to empower these business teams to decarbonize.

1.3 Purpose and Motivation of Project

This project aims to explore the challenge of internal carbon allocation which many companies are facing today, and develop a carbon allocation mechanism for business activities which multiple business teams contributed to. Amazon is one of many large companies that are facing such challenge. Amazon is a global online retailing/tech company that has been continuously growing, ever since it was established in 1994. The company has many different business teams with interdependencies, which makes this project a great opportunity for Amazon to study and potentially implement into their business, as the whole company continues to grow. We provide a more detailed overview and background of the company in Chapter 2.

1.4 Problem Statement

Today, Amazon calculates and tracks its carbon footprint emitted by internal business teams that own physical assets (e.g., vehicles and facilities). Additional efforts are being made to internally standardize allocation of carbon footprint in order to empower business teams without direct emissions, so that it will allow them to own their decarbonization journey. Business teams are currently measuring and tracking their decarbonization improvement by mapping different denominators as a Carbon Intensity metric (e.g., gCO_2eq per item, per package, per pallet, per tote, per $GMS). Using this metric help each business team to understand how much progress it made so far and take actions to decarbonize at business team-level. However, at company-level, having inconsistent metrics often hinders the team's ability to compare and understand the actual decarbonization improvement achieved across different business teams, which inhibits their understanding of the best decisions for the business considering end-to-end connections.

1.5 Project Goals

Focusing on transportation businesses at Amazon, we aim to recommend a standardized solution to allocating carbon emissions for shared physical assets in transportation (e.g., delivery trucks). We believe that this will be an important mechanism to empower business teams with strong dependencies on assets managed by central teams by enabling a fair and standardized carbon entitlement. Knowing the actual entitlement will encourage ownership and responsibility over their collective decarbonization strategy. In addition, the carbon allocation methodology can be extended for external reporting regulatory compliance, by enabling carbon entitlement for specific legal entities. Our goal is to propose a simple carbon allocation methodology for transportation business at Amazon, which could later be expanded to other non-transportation businesses (e.g., corporate buildings, facilities and servers).

Chapter 2: Company Background

In this Chapter, we provide historical and cultural background of Amazon.com, Inc (Amazon). We also dive into its sustainability goals and plans (Climate Pledge), and review its sustainability report from the past 3 fiscal years.

2.1 Overview of Amazon.com, Inc.

Amazon was founded by Jeff Bezos in July 1994, which originally began as a website that only sold books; however, Bezos had a clear vision from the beginning to grow the company into “an everything store”[7]. By the end of 1997, Amazon served more than 1.5 million customers and grew its revenue from $15.7 million in 1996 to $147.8 million (838% increase)[8]. Starting in 1998, they began expanding their business beyond books; they added music (CDs and DVDs), clothing, electronics, kitchenware, etc[9]. Today, Amazon not only sells physical goods online, but also owns and operates grocery stores (e.g., Whole Foods, Amazon Go), creates its own technology and devices (e.g., Kindle, Amazon Echo, Alexa), and provides web services to millions of customers (e.g., AWS). By the end of 2020, their annual net sales and net income reached $386 billion and $21.3 billion, respectively[10] (Figure 1).

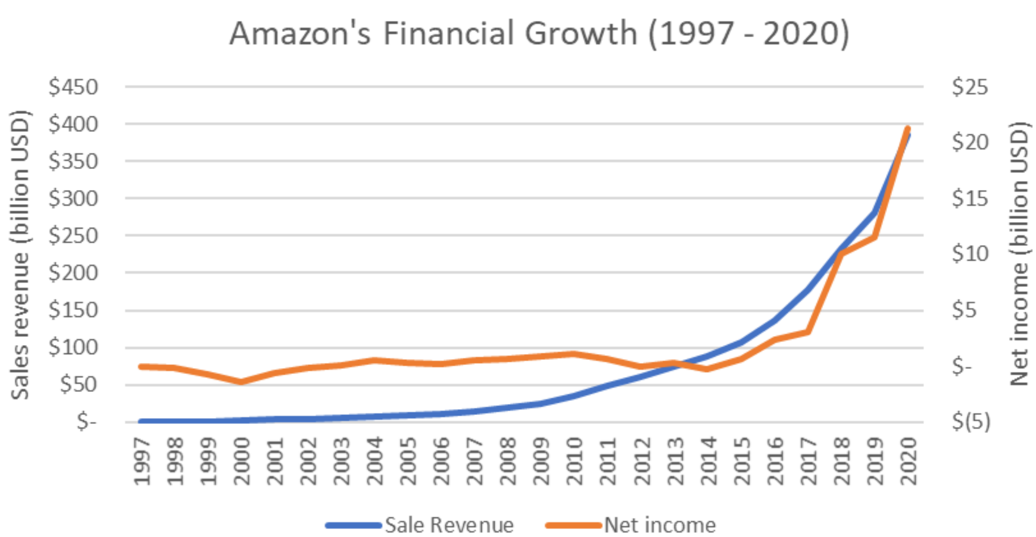


Figure 1: Amazon's financial growth since 1997

2.2 Company Culture

Amazon is known for its unique company culture. In this subsection, we introduce Amazon's 2 work culture philosophies that are deeply rooted in the company's DNA.

"Day 1" Philosophy

Over the past 27 years since its establishment, Amazon has grown from a small startup in Bezos' home garage in Seattle to a global tech giant that employs 1.3 million people around the world[10]. The key to their continuous growth lies in Bezos' "Day 1" philosophy. In his 2016 Letter to Shareholders, he states;

> *"Day 2 is stasis. Followed by irrelevance. Followed by excruciating, painful decline. Followed by death. And* that *is why it is* always *Day 1."*[8]

In the same letter, he encourages employees to continue experimenting and innovating until seeing customer delight, make quick decisions, and be curious about new external trends.

16 Leadership Principles

Another integral part of Amazon's culture lies in its "Leadership Principles" (or LPs). Bezos announced the original 14 LPs in 2015 (1 – 14 in the list below). In July 2021, he added 2 more LPs to the list (15. "Strive to be Earth's Best Employer" and 16. "Success and Scale Bring Broad Responsibility").

<u>Amazon's 16 Leadership Principles</u>[11]

1. Customer Obsession
2. Ownership
3. Invent and Simplify
4. Are Right, A Lot
5. Learn and Be Curious
6. Hire and Develop the Best
7. Insist on the Highest Standards
8. Think Big
9. Bias for Action

10. Frugality
11. Earn Trust
12. Dive Deep
13. Have Backbone; Disagree and Commit
14. Deliver Results
15. Strive to be Earth’s Best Employer
16. Success and Scale Bring Broad Responsibility

2.3 Amazon’s Supply Chain

Online retail has been Amazon’s key business ever since its founding. The company has expanded its delivery routes and warehouse locations over the years, delivering packages to customers all over the world. In 2020, Amazon delivered 4.2 billion parcel shipments, making it one of the top deliverers of parcel shipments[12].

In order for an Amazon’s package to be delivered at customer’s doorstep safely and on time, it goes through multiple steps in the company’s complex supply chain. Below is a simplified-version of the company’s supply chain, followed by explanation of each step (Figure 2).

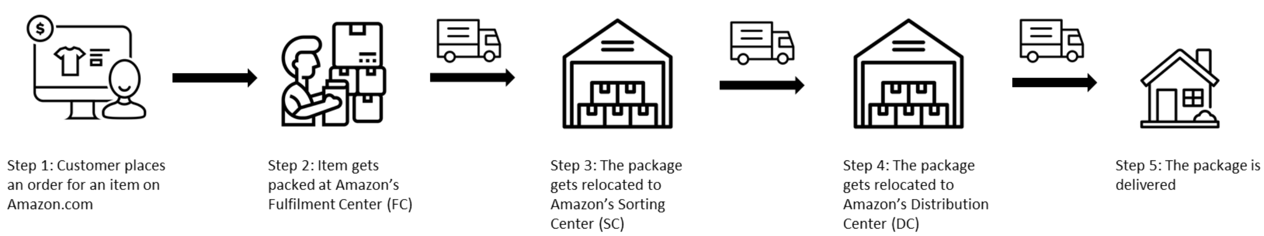


Figure 2: Simplified diagram of Amazon's supply chain

Step 1 to 2: Customer’s “click” to Fulfillment Center

After a customer purchases an item(s) via Amazon.com, the order is processed and sent to an Amazon’s fulfilment center (FC), a big warehouse where inventory of these items is stored. There are 175 Amazon FCs operating globally today, which covers more than 150 million square feet of space[13]. Items are put into yellow bins, travel for miles within the FC on a conveyor belt, and then get packed into a box.

Step 2 to 3: Fulfillment Center to Sorting Center

Packages leave the FC and get transported to Amazon's sorting center (SC), a facility for sorting packages by its final destination. This intermediate step was created as part of their effort to optimize their supply chain.

Step 3 to 4: Sorting Center to Distribution Center

Packages leave the SC and get transferred to Amazon's distribution center (DC), a facility for sorting packages by its final destination and loading them on last mile delivery trucks.

Step 4 to 5: Distribution Center to Customer

After packages leave the DC, last-mile delivery truck delivers these packages one by one to their final customers.

Steps 2 to 4 are usually done within Amazon's established network and were built to optimize deliveries for speed and cost. This range is called the "middle mile" (MM) of Amazon's supply chain. The final step of the supply chain (between Step 4 and Step 5) is called the "last mile" (LM).

Throughout this process, multiple internal/external stakeholders work together to have a package safely delivered to its customer (Figure 3). For example, facilities team owns the warehouses and manages its daily operation; transportation team owns and operates the vehicles that carry inventory and packages between nodes of the supply chain; supply chain team manages and runs the algorithm that determines the optimized route the package will travel, etc.

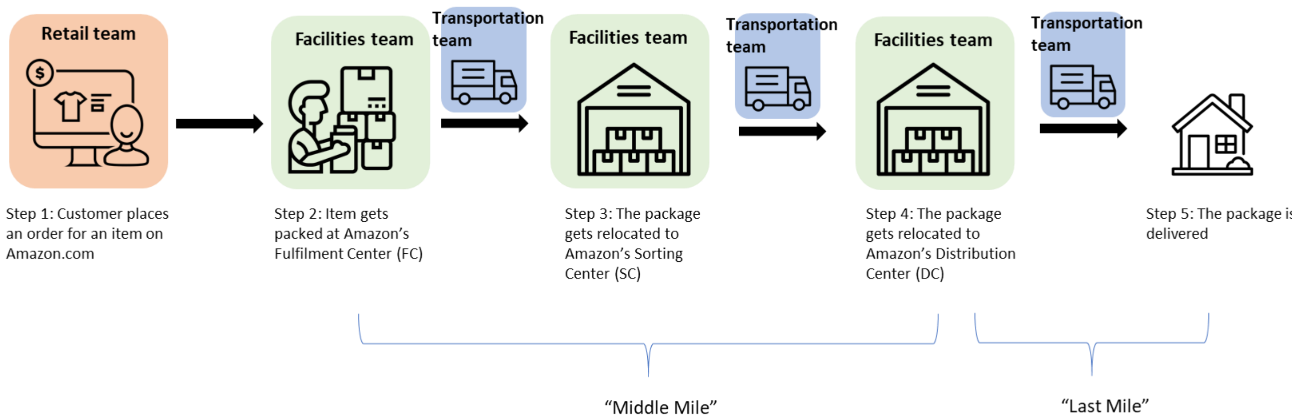


Figure 3: Multiple teams in the supply chain

2.4 Sustainability at Amazon

2.4.1 Climate Pledge and Amazon's Net Zero Plan

In 2019, Amazon co-founded the Climate Pledge, in which Amazon and other members committed to achieve net-zero carbon by 2040, 10 years ahead of Paris Agreement. As of today, the Climate Pledge has more than 200 signatories across 26 industries and 21 countries. The signatories agrees to follow 3 principal areas to take action towards net-zero carbon goals[14];

1. ***Regular Reporting***

   "Measure and report greenhouse gas emissions on a regular basis"

2. ***Carbon Elimination***

   "Implement decarbonization strategies in line with the Paris Agreement through real business changes and innovations, including efficiency improvements, renewable energy, materials reductions, and other carbon emission elimination strategies."

3. ***Credible Offsets***

   "Neutralize any remaining emissions with additional, quantifiable, real, permanent, and socially-beneficial offsets to achieve net-zero annual carbon emissions by 2040."

In order to achieve net-zero carbon by 2040, Amazon has made multiple midterm goals, such as converting power supply for their operations to 100% renewable energy by 2025 and making 50% of all shipments net-zero carbon by 2030 ("Shipment Zero"). They are also investing $2 billion total via their Climate Pledge Fund into innovative technologies and services that could contribute to decarbonization. In addition, Amazon joined SBTi in May 2020 and has committed to reporting their science-based targets in 2022. Unlike some companies that are trying to achieve net-zero carbon by purchasing carbon credits and offsetting their actual carbon emission, Amazon's aim is to make physical decarbonization its top priority and use offset as very last option.

2.2.2 Amazon's Current Status on Sustainability

Amazon measures and tracks both direct and indirect operational activities to quantify their carbon footprint. They track and report total carbon footprint and carbon intensity metric (grams of CO_2-equivalent GHG emitted, "gCO_2eq", per dollar of gross merchandise sales, "$GMS") to provide different perspectives of their footprint. During the COVID-19 pandemic, Amazon's business grew greatly due to significant increase in customer online orders, which contributed to 19% increase in total carbon emission in 2020 (60.64 million metric ton CO_2eq) compared to 2019 (51.16 million metric ton CO_2eq). However, when we compare carbon intensity (gCO_2eq/$GMS) instead of aggregate amount of carbon emission, it drops by 16% in 2020 (102.7 gCO_2eq/$GMS) compared to 2019 (122.9 gCO_2eq/$GMS). See Table 1 for breakdown of Amazon's carbon footprint.

There are multiple reasons that explain this decrease in carbon intensity, despite Amazon's business growth amid the pandemic. First, customers made fewer trips to Amazon's physical stores (e.g., Whole Foods) and switched to home delivery. With home delivery method, multiple customers' orders can be dealt with at once, which makes it a low-carbon alternative for the company. Second, Amazon employees made fewer corporate travels due to COVID-19 pandemic restrictions. Third, the company started to take action in minimizing their carbon footprint (e.g., reducing packaging materials, increasing efficiencies in their transportation network, using renewable energy to power their fulfillment facilities).

This reduction in carbon intensity is a product of both external forces (e.g., COVID-19 pandemic) and Amazon's internal effort to reduce carbon emission. However, focusing only on carbon intensity to track a company's decarbonization journey could potentially trigger a reverse effect known as "Jevons paradox". Jevons paradox is a phenomena in economics which states "in the long term, an increase in efficiency in resource use will generate an increase in resource consumption rather than a decrease"[15]. In Amazon's case, online purchases and other businesses (e.g., AWS) will likely to continue growing, hence the total amount of carbon emission will likely to increase as a result. Their challenge will be in achieving net-zero carbon despite their continued growth.

Amazon's Enterprise-Wide Carbon Footprint, 2018 - 2020

Emission Category (million metric tons CO_2eq)	2018	2019	2020	YOY%
Scope 1 - Direct Emissions	**4.98**	**5.76**	**9.62**	**67%**
Fossil fuels	4.7	5.57	9.37	68%
Refrigerants	0.28	0.19	0.25	32%
Scope 2 - Purchased Electricity	**4.71**	**5.5**	**5.27**	**-4%**
Scope 3 - Indirect Sources	**34.71**	**39.91**	**45.75**	**15%**
Corporate purchases and Amazon-branded product emissions (e.g., operating expenses, business travel, Amazon-branded product manufacturing, use phase, end-of-life)	11.95	15.41	16.7	8%
Capital goods (e.g. building construction, servers and other hardware, equipment, vehicles)	4.64	8.01	10.52	31%
Other indirect emissions (e.g., third-party transportation, packaging, upstream energy related)	13.89	12.44	15.77	27%
Lifecycle emissions from customer trips to Amazon's physical stores	4.23	4.05	2.77	-32%
Amazon's Total Footprint (Scope 1 + 2 + 3)	**44.4**	**51.17**	**60.64**	**19%**
Carbon Intensity (grams of CO2eq per GMS)	**128.9**	**122.8**	**102.7**	**-16%**

Table 1: Amazon's carbon footprint, 2018-2020[16]

Chap 3: Literature review

In this chapter, we dive into concepts and topics that are related to this project. Specifically, we will summarize the GHG Protocol, review 3 methods to calculate carbon footprint for transportation activities, and introduce different ways to reduce carbon emission in transportation.

3.1 Summary of GHG Protocol

GHG Protocol is a global carbon accounting framework for companies to measure and disclose their annual GHG emission deriving from business operations. It was established by WRI and WBCSD in the late 1990s, when they recognized the need for international guideline for carbon accounting and standardized measurement of GHG emissions[17].

The requirements and guidelines for companies to follow in order to prepare and disclose their GHG emissions inventory are provided in "GHG Protocol Corporate Accounting and Reporting Standard (CARS)"[18]. According to CARS, GHG emission from a reporting company's operation can be categorized into 3 scopes – Scope 1 (Direct GHG emissions), Scope 2 (Electricity indirect GHG emissions), and Scope 3 (Other indirect GHG emissions).

Scope 1 (Direct GHG emissions) includes GHG-emitting activities from assets legally owned by the reporting company, e.g., transportation of materials or products on vehicles owned or controlled by the company, physical or chemical processing in manufacturing. For Amazon, GHG emitted by Amazon-owned trucks are categorized under Scope 1 emission.

Scope 2 (Electricity indirect GHG emissions) is a category for electricity that the reporting company purchased from an electricity company and consumed for its operation. This scope is considered as a type of "indirect" emissions, since GHG emission from generation of electricity occurs before it is purchased, i.e., the reporting company's operation did not directly contribute to GHG emission from generation of electricity. An example of activities in Amazon that fall under Scope 2 is purchase of electricity consumed for lightings and air conditioning in Amazon-owned buildings and electric vehicles.

Scope 3 (Other indirect GHG emissions) is considered an "optional reporting category", which includes all other indirect emissions that do not fall under Scope 2. For Amazon, this includes activities such as transportation done by third parties, including deliveries done by other transportation companies (e.g., UPS, FedEx) and customers' travel to Amazon's physical stores, and employees' corporate travels.

This categorization framework by activity types allows companies to not only understand the origin of their carbon footprint, but also to avoid double counting among other companies and to develop a decarbonization strategy based on breakdown of its footprint. For example, IKEA, a global home furniture and retail company, calculated their GHG emission according to CARS and found that 66% of its emissions come from customer travel, which falls under Scope 3 emissions. As part of their effort to decarbonize, IKEA now provides home delivery services for customers, which not only provides convenience and options for customers, but also cuts down the company's overall GHG emission (i.e., one truck can carry and deliver products to multiple customers at once)[19].

It is important to note that transportation-related activities appear in all three scopes of GHG emission; Scope 1 for company-owned vehicles, scope 2 for charging electric vehicles, and scope 3 for third-party contracted transportation and distribution (Figure 4). In fact, transportation was the biggest source of CO_2 emission in the U.S. in 2019, contributing to 35% of total CO_2 emissions, according to IPCC[20] (see Appendix 1 for details). This goes to show how influential transportation sector is to climate change, and that making innovative improvements to decrease emission in transportation has big positive impact to tackling global warming.

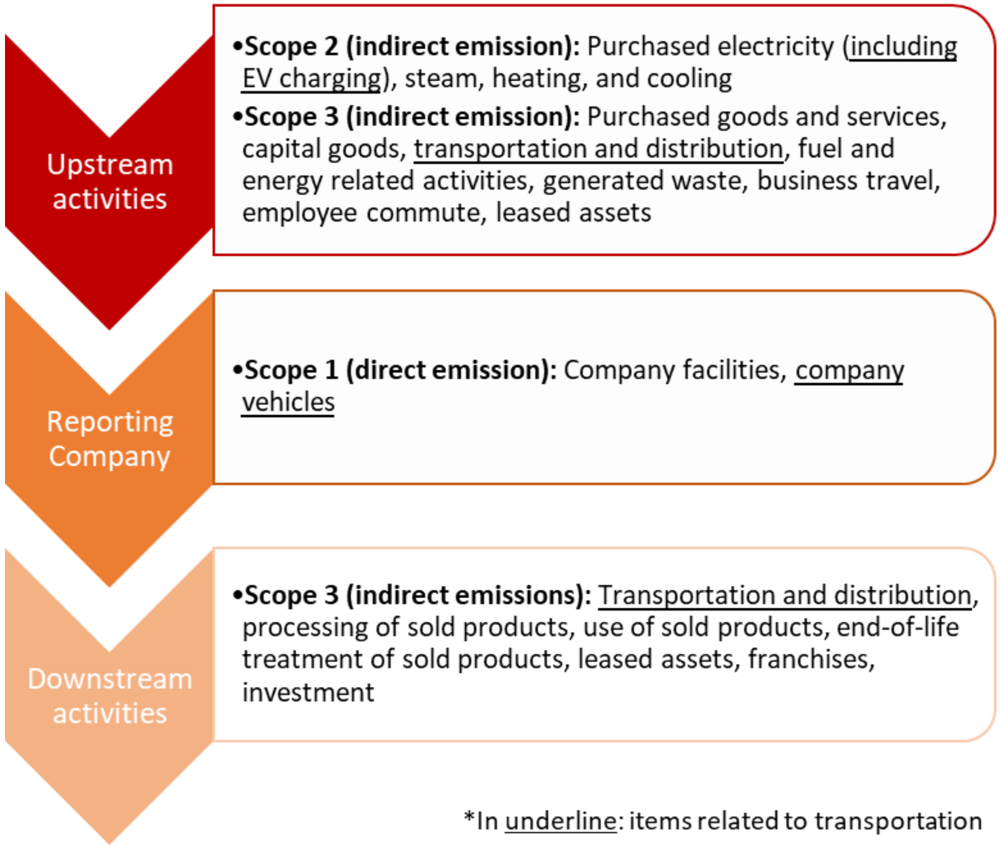


Figure 4: Overview of GHG Protocol[21]

3.2 Carbon Footprint Calculation for Transportation Activities

According to GHG Protocol, there are three main ways to calculate carbon footprint for transportation activities; fuel-based method, distance-based method, and spend-based method[22].

- ***"Fuel-based method"*** calculates carbon emission of a trip by determining the amount of fuel consumed, and applying a fuel-specific emission factor.
  GHG emission (fuel-based) = amount of fuel consumed [gallons] x fuel-specific emission factor [gCO_2eq per gallon]

- ***"Distance-based method"*** calculates carbon emission of a trip by determining the weight, distance travelled, and mode of shipment of the trip, and then applying a vehicle-specific mass-distance emission factor.

GHG emission (distance-based) = travelled distance [miles] x weight of shipment [tons] x emission factor [gCO_2eq per ton-mile]

- ***"Spend-based method"*** calculates carbon emission of a trip by determining how much money was spent on each mode of transport and applying Environmental Extended Input-Output (EEIO) emission factor.
  GHG emission (spend-based) = amount paid for fuel consumed during the trip [US$] x EEIO emission factor [gCO_2eq per US$]

Which calculation method to use depends on what activity data categories are available within the reporting company's data base. GHG Protocol provides a guideline on how to decide which calculation method to use, as per decision tree diagram in Figure 5 below. As the decision tree diagram implies, it is generally recommended to prioritize and use fuel-based or distance-based method of calculation instead of spend-based, since those two methods use physical data and are perceived to be more accurate.

Figure 5: Decision tree diagram for calculating carbon emission in transportation[22(p4)]

3.3 GHG Emission Reduction in Transportation

As we introduced in subsection 3.2, GHG emission from a trip is affected mainly by amount of fuel consumed, distance travelled, and weight of shipment. By finding ways to reduce one or more of these variables, it could potentially lead to reduction in GHG emission. We introduce multiple ways one could reduce GHG emission in transportation below;

- ***Improving vehicle efficiency:*** There is many research being done to improve vehicle efficiency, including improving combustion strategies, minimizing unnecessary idling from vehicles, using more lightweight materials for vehicles (e.g., aluminum, carbon fiber), and improving aerodynamics of vehicles to reduce energy lost to non-engine sources (e.g., drag, braking, rolling resistance)[23].

- ***Fuel switching***: With advancement in technology, it has become possible to operate vehicles in alternative source of energy that has lower carbon emission compared to traditional gasoline, e.g., electricity, natural gas, ethanol.
- ***Route optimization***: By optimizing the route to minimize the overall travel distance, both operational cost (including fuel) and time could be reduced. For delivery business, this optimization can also be achieved by minimizing empty space (in other words, increasing utilization rate of the vehicle space), so that total number of trips can be reduced.

Chap 4: Carbon Allocation Logic

As discussed in subsection 2.2.2., choosing a carbon intensity (CI) unit to track and allocate GHG emission from a single business activity to multiple internal business teams could have both positive and negative consequences to a company's long-term decarbonization goal, depending on the denominator used to calculate CI. In this chapter, we introduce carbon allocation logics that use different CI units for transportation activities to allocate GHG emission to business teams that share physical assets and contribute to the same activity (subsection 4.1), compare these logics using a hypothetical example (subsection 4.2), and explore the pros and cons of each logic (subsection 4.3).

4.1 Introduction to Carbon Allocation Logics

In transportation, there are multiple CI units that could be used to allocate GHG emission from a single trip to business teams that contributed to the trip. This situation happens when different business teams use the same truck to deliver packages to their customers. The simplest way to allocate GHG emission is by using package/item count as denominator for CI calculation (subsection 4.1.1). However, not all packages or items share the same physical characteristics, e.g., cubic volume and weight. To add to the complexity, packages could be loaded onto and/or offloaded from a vehicle at different locations, therefore not all packages may have travelled the same distance, e.g., last-mile deliveries. We chose cubic volume (subsection 4.1.2), weight (subsection 4.1.3), and distance travelled (subsection 4.1.4) in addition to package/item count as variables for carbon allocation logics. We also explored weight-distance (subsection 4.1.5), which is a commonly used unit in transportation industry to measure and track carbon footprint.

4.1.1 Per Package/Item Count Logic

This is the simplest logic, where total GHG emission of the trip is divided by the total number of packages or items that were on the vehicle. The benefit of this logic is how it does not require large data collection to perform the logic. For that reason, many transportation business teams use gCO_2eq per package/item count as their business KPI. However, this logic does not take each package's physical properties into account, which could cause "unfair" allocation among packages of different sizes, weights, and distance travelled.

4.1.2 Per Cubic Volume Logic

In this logic, total GHG emission of a trip is divided by the total cubic volume of packages that were on the vehicle. The benefit of this logic is that unlike package count logic introduced in subsection 4.1.1, it takes physical size of packages into account and allocates more carbon accountability to bigger sized packages. Every vehicle has limited volume capacity, e.g., the number of packages that can be loaded on a vehicle depends on the size of those packages, so it makes sense to hold the size of packages accountable for every gram of GHG emitted during a trip. One downside to this logic is the potential issue with data quality, since all three dimensions of packages need to be measured precisely in order to calculate the correct volume.

4.1.3 Per Weight Logic

This logic is similar to per volume logic introduced in subsection 4.1.2, but uses package weight instead of package volume to allocate carbon. The benefit of this logic is that weight is easier to measure than cubic volume, i.e., weight only requires one data point unlike volume, which requires data from 3 dimensions. Also, the total weight of shipment is used to calculate GHG emission for transportation in distance-based method (as per subsection 3.2), so one could argue that heavier packages should be held accountable for more carbon than lighter packages. On the other hand, unlike volume, weight is a less likely factor to limit how many packages can be loaded onto a vehicle, considering how a typical Amazon package is significantly lighter than weight limit of a delivery truck.

4.1.4. Per Distance Travelled Logic

In this logic, carbon will be allocated according to the distance that each package travelled during the trip. This logic is ideal for trips where packages get loaded and/or off-loaded in different locations during the trip (e.g., LM delivery). However, this logic is not ideal for trips that load and off-load all packages in same locations (e.g., MM trip). If all packages travel the same distance, this means that GHG emission will be allocated equally among packages, showing the same outcome as per package logic in subsection 4.1.1.

4.1.5 Per Weight-Distance Logic

"gCO_2eq per weight-distance (e.g., ton-mile)" is a carbon intensity unit that transportation industry often uses for tracking its carbon footprint, since GHG emission of a vehicle can be calculated by distance-based method (as per subsection 3.3). This metric is well suited for informing vehicle efficiency of a trip.

4.2 Comparison of Different Carbon Allocation Logics

To understand how the outcome of carbon allocation differs depending on the logic used, we compare the above logics using a hypothetical example, shown in Figure 6 below. In this example, we assume a last-mile delivery truck carrying 2 packages of different sizes (Package A and Package B), each being delivered to end customers in different locations. In subsection 4.2.1, we will explain how to utilize the logics using the example in Figure 6, and in subsection 4.2.2, we will do a pros and cons comparison of these different logics.

Package	Item	# of items	Volume (cft)	Weight (lbs)	Distance* (miles)
A	Giant teddy bear	1	130	20	5
B	20-lb dumbbell x 3	3	1	60	10

*Assume distance from fulfillment center to customer, not end-to-end

Figure 6: Example of last mile delivery

4.2.1 Using Carbon Allocation Logics in Hypothetical Example

Below, we walk through step by step how to calculate and allocate carbon emission for packages A and B in each logic. Note that we do not discount the amount of carbon allocated to packages for empty space (i.e., space on the truck that was not filled by packages).

Per package/item count logic

In this logic, the physical information of packages/items do not matter in carbon allocation. Since there are 2 packages total on the truck that emitted 20 kgCO_2eq of GHG during the trip, each package will be allocated 10 kgCO_2eq from the trip when using per package logic. In per item logic, since there are 4 items in total, 5 kgCO_2eq will be allocated to each item (i.e., Package A = 5 kgCO_2eq, and Package B = 15 kgCO_2eq).

Per cubic volume logic

The 2 packages in Figure 6 have different volumes; Package A = 130 cubic feet (cft), and Package B = 1 cft. Since 20 kgCO_2eq of GHG was emitted to deliver 131 cft of total package volume, 0.15 kgCO_2eq (= 20 kgCO_2eq / 131 cft) will be allocated to each cft of package, i.e., Package A = 19.8 kgCO_2eq, and Package B = 0.2 kgCO_2eq.

Per weight logic

Similar to 4.2.2, the 2 packages have different weights; Package A = 20 pounds (lbs.) and Package B = 60 lbs. Therefore, 0.25 kgCO_2eq (= 20 kgCO_2eq / 80 lbs.) of GHG will be allocated to each pound of package, i.e., Package A = 5 kgCO_2eq and Package B = 15 kgCO_2eq. In this logic, Package B accounted for more carbon emission than Package A due to its high density, which is opposite outcome compared to per volume logic.

Per distance travelled logic

Packages A and B travelled different distances, since packages in last-mile delivery trucks get dropped off at different destinations. In this example, Packages A and B travelled 5 miles and 10 miles, respectively. This means that for every mile travelled by a package, approximately 1.33 kgCO_2eq (= 20 kgCO_2eq / 15 miles) of GHG will be allocated, i.e., Package A = 6.7 kgCO_2eq, Package B = 13.3 kgCO_2eq.

Per weight-distance logic

For this logic, we multiply each package's weight and distance travelled to "weight-distance" unit. For example, weight-distance of Package A is 100 lbs.-miles (= 20 lbs. x 5 miles) and Package B is 600 lbs.-miles (=60 lbs. x 10 miles). This means that for every mile that a pound of package travelled, the vehicle emitted approximately 0.029 kgCO_2eq of GHG. Using this unit, Packages A and B will be allocated 2.9 kgCO_2eq (= 0.028 kgCO_2eq/lb.-miles x 100 lbs.-miles) and 17.1 kgCO_2eq (= 0.029 kgCO_2eq/lb.-miles x 600 lbs.-miles) of GHG, respectively.

4.2.2 Pros and Cons Comparison

As seen in the example from subsection 4.2.1, how much GHG emission each package holds accountable for depends on what variable was used for CI calculation (Table 2). The key to choosing the "right" logic for tracking and allocating GHG emission among multiple internal business teams depends on feasibility (e.g., data availability and accuracy) and short-term/long-term impact and consequences it has on company's sustainability goals (e.g., using a certain CI unit for a business team's KPI may drive efficiency but not actual decarbonization, as described in Jevons Paradox in subsection 2.2.2.).

Carbon allocated per logic [unit: kgCO2eq]	**Package A**	**Package B**	**Difference (A - B)**
Per package (4.2.1)	10.0	10.0	0.0
Per item (4.2.1)	5.0	15.0	-10.0
Per cubic volume (4.2.2)	19.8	0.2	19.7
Per weight (4.2.3)	5.0	15.0	-10.0
Per distance travelled (4.2.4)	6.7	13.3	-6.7
Per weight-distance (4.2.5)	2.9	17.1	-14.3

Table 2: Summary of carbon allocation results

Each logic's pros and cons are summarized in the table below (Table 3), based on its feasibility and impact on company's sustainability goals.

Logic	Pros	Cons
Per package/item count	Very simple logic and no need for large data collection; "carbon per package" is commonly used as KPI in transportation business teams.	Does not take package's physical properties (e.g., cubic volume and weight) into account. This logic only makes sense if all packages/items are the same size
Per cubic volume	Volume is often the limiting factor for loading packages onto a vehicle. It is also used by most businesses for their KPIs.	Data quality is a potential issue, since all 3 dimensions of the package (length, width, height) need to be measured accurately to get the correct volume.
Per weight	Relationship between mass of vehicle vs carbon emission is well studied (e.g., heavier the vehicle, more carbon it emits for every km it travels). EU has put regulation on car manufacturers to reduce the weight of cars due to that correlation.	Transportation businesses don't track package weight as KPI today, since most trips do not cap out at weight due to the nature of transportation parcels (package weight <<< vehicle weight)
Per distance travelled	Carbon emission of trip can be calculated by multiplying distance and emission factor (in distance-based method).	Package-level distance for each trip not available in Amazon's database (only trip distance, which may not be exactly be the same as package distance especially for LM deliveries). If all packages travelled the same distance like in MM trips, then this logic will have the same outcome as per package logic.
Per weight - distance (e.g., ton-mile)	Commonly used in the transportation industry for carbon intensity unit, since distance-based GHG calculation for transportation is "distance x weight x vehicle-specific emissions factor"	Needs both weight and distance package-level data in order for this logic to work. The outcome will be the same as per weight logic if all packages travelled the same distance.

Table 3: Summary of Carbon Allocation Logic Comparison

Chap 5: Research Methodology

Using the same methodology introduced and explained in subsection 4.2, we tested each carbon allocation logic on Amazon's actual activity data from past trips. In this chapter, we explain the steps taken to conduct the analysis.

5.1 Summary of steps taken

To understand and determine how to utilize the different carbon allocation logics, each logic was tested on actual historical trip data that was available in Amazon's data base. First, necessary data was collected by querying on Amazon's SQL data interface. After cleaning the data, different carbon allocation logics were tested on each trip in Microsoft Excel. To understand and compare the outcome of different logics, data visualization (box and whisker plot and violin plot) was done in R. Lastly, causal loop diagram to understand and forecast the short-term/long-term impact when using a certain carbon allocation logic as a centralized method to track and allocate carbon in Amazon's transportation business.

5.2 Data collection

To test the different logics on historical trip data, we determined the data categories necessary for each logic (Table 4).

Data category name	Explanation/exmaples of data category	Logic type				
		Package/ item count	Cubic volume	Weight	Distance travelled	Weight-distance travelled
Region	Country where the trip happened	✓	✓	✓	✓	✓
Trip type	E.g., first mile, middle mile, last mile	✓	✓	✓	✓	✓
Trip ID	Unique identification code given to the trip	✓	✓	✓	✓	✓
Vehicle Type	E.g., 53-foot truck	✓	✓	✓	✓	✓
GHG emission of trip	Amount of GHG emitted from the trip	✓	✓	✓	✓	✓
# of packages	Total amount of packages on the trip	✓	✓	✓	✓	✓
# of items	Total amount of items on the trip	✓				
Package volume	Volume of each package		✓			
Package weight	Weight of each package			✓		✓
Distance travelled	Distance travelled for each package				✓	✓

Table 4: Data categories for each logic

Using Amazon's SQL data base, data for multiple trips were queried. For this study, we focused on testing the logics on MM and LM trips. MM trips typically transport packages from one Amazon facility to the other, so all packages travel the same distance. On the other hand, LM trips are for delivering packages from Amazon facility to end customers, so distance differs for each package since they get dropped off at different locations. Trip data used for this project were randomly selected from the US, United Kingdom (UK), and Germany (DE) (Table 5).

#	Region	Trip type	Shipment Date	Vehicle Type
1	US	MM	3/3/2020	FIFTY_THREE_FOOT_TRUCK
2	US	MM	3/19/2020	FIFTY_THREE_FOOT_TRUCK
3	US	MM	5/12/2020	TWENTY_SIX_FOOT_BOX_TRUCK
4	US	MM	7/9/2020	SKIRTED_FIFTY_THREE_FOOT_TRUCK
5	US	MM	9/16/2020	CUBE_TRUCK
6	US	MM	12/9/2020	FIFTY_THREE_FOOT_TRUCK
7	UK	MM	1/2/2019	DETACHED_TRAILER
8	UK	MM	7/3/2020	DETACHED_TRAILER
9	UK	MM	7/15/2020	DETACHED_TRAILER
10	UK	MM	10/17/2020	DROP_TRAILER
11	DE	MM	6/7/2021	DROP_TRAILER
12	DE	MM	6/4/2020	DETACHED_TRAILER
13	DE	MM	3/25/2020	DROP_TRAILER
14	DE	MM	12/12/2020	DETACHED_TRAILER
15	US	LM	1/13/2020	SMALL_BOX_TRUCK
16	US	LM	3/5/2020	STANDARD_CARGO_VAN
17	US	LM	5/11/2020	EXTRA_LARGE_CARGO_VAN
18	US	LM	7/5/2020	LARGE_CARGO_VAN
19	US	LM	9/2/2020	STANDARD_CARGO_VAN
20	US	LM	11/20/2020	LARGE_CARGO_VAN

Table 5: Summary of trips used for data analysis

During this step, there were 2 main limitations that became clear. First, data for business team of each package was not available in the data base we used, due to the company's confidentiality reasons. Second, data on package-level distance travelled for both middle mile and last mile trips were not available on tables we were able to gain access to. These limited our scope to testing only 3 logics (package/item count, cubic volume, and weight), and without business team information for each package, we were not able to test the actual impact each allocation logic would have on business team's GHG accounting.

5.3 Testing carbon allocation logics

Using the historical trip data collected in subsection 5.2, different carbon allocation logics were tested using Microsoft Excel.

5.3.1 Per package/item count

Total GHG emission of the trip was divided by the total number of packages (or items) on the trip, which was then allocated to each package (or item).

5.3.2 Per cubic volume

Total GHG emission of the trip was divided by total volume of packages on the trip. The CI unit (e.g., gCO_2eq/cft) was then multiplied by each package's volume to determine how much carbon to allocate to each package. It is important to note that we did not divide the carbon emission by the vehicle's total volume capacity, which would include empty space (i.e., space that was not filled by packages). This means that each package bears the cost of not filling up the truck to its maximum capacity.

5.3.3 Per weight

Total carbon emission of the trip was divided by the total weight of packages on the trip. The outcome (e.g., $gCO_2eq/lbs.$) was then multiplied by each package's weight to allocate.

5.4 Data visualization techniques used

5.4.1 Box and whisker plot

Box and whisker plot (or box plot) is a data visualization technique used to display data distribution in multiple quartiles. It is a useful technique that shows the minimum, first quartile, median, third quartile, maximum, outlier, spread, and skewness of a data set with more than 5 observations in one graph[24]. It consists of two main structures (Figure 7);

1. *Box*: also known as "interquartile range" (or IQR), the box covers data distribution between 25th percentile (or 1st quartile, Q1) and 75th percentile (or 3rd quartile, Q3), with a line that indicates the median.

2. *Whisker*: the lines extending from the two ends of the Box are called "whiskers", which indicates the lower and upper quartiles outside of the Box. The outliers, defined as Q1 – 1.5 x IQR or Q3 + 1.5 x IQR, are plotted as individual dots beyond the whiskers.

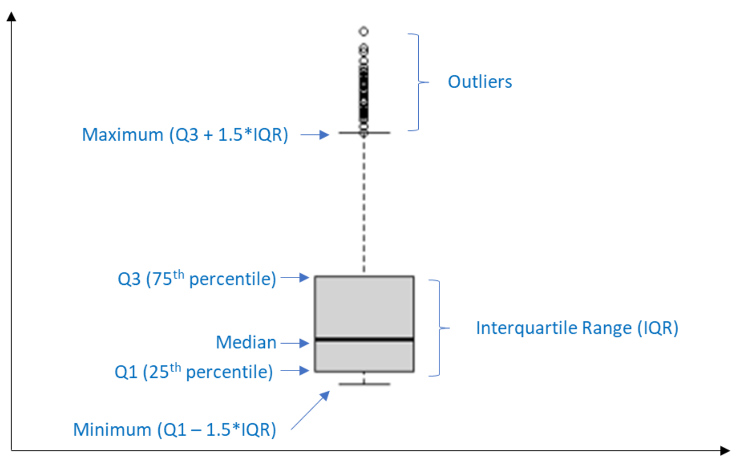


Figure 7: Box and whisker plot[25]

5.4.2 Violin plot

Violin plot is another data visualization technique used for showing data distribution. In addition to the information provided in a typical box plot, a violin plot also shows how data density is distributed along the data points. Figure *8* compares a violin plot to a box plot.

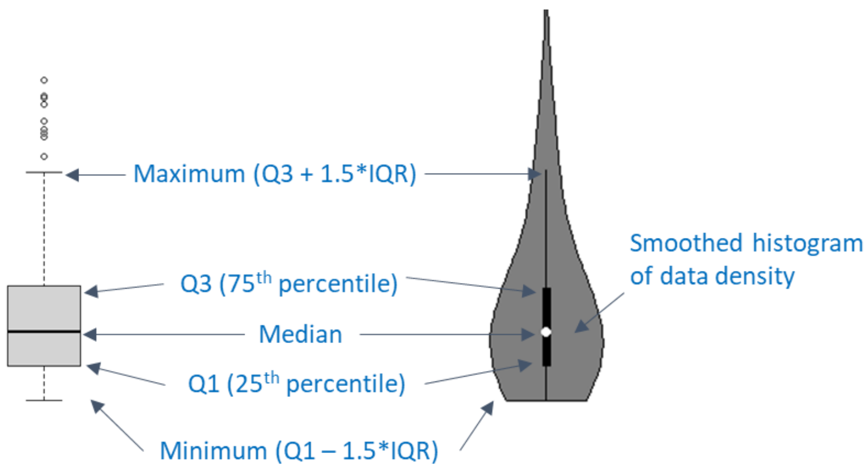


Figure 8: Comparison of box plot and violin plot[24]

The purpose of using box and violin plots for this project is to visualize and compare the distribution of carbon allocated to each package in different carbon allocation logics. For example, in per package logic, there will be only one dot or line on the plot since all packages on the trip will be allocated equal amount of carbon. On the other hand, we expected to see a wider distribution of carbon allocated to each package when using per volume or weight logics, since each package will be allocated different amount of carbon, depending on its size/weight.

Chap 6: Results and Discussion

In this chapter, we present the results from applying different carbon allocation logics to Amazon's historical trip data as summarized in Table 5, and discuss how to utilize the findings to develop a carbon allocation methodology for transportation teams at Amazon.

6.1 Overview of Amazon's packages

Before testing different carbon allocation logics to Amazon's trip data, we investigated the frequency distribution of Amazon package's volume and weight. We were able to obtain both weight and volume data on X million packages that Amazon sold in North America since 2019. Using that data, we analyzed the distribution of package weight and package volume, respectively (Figure 9).

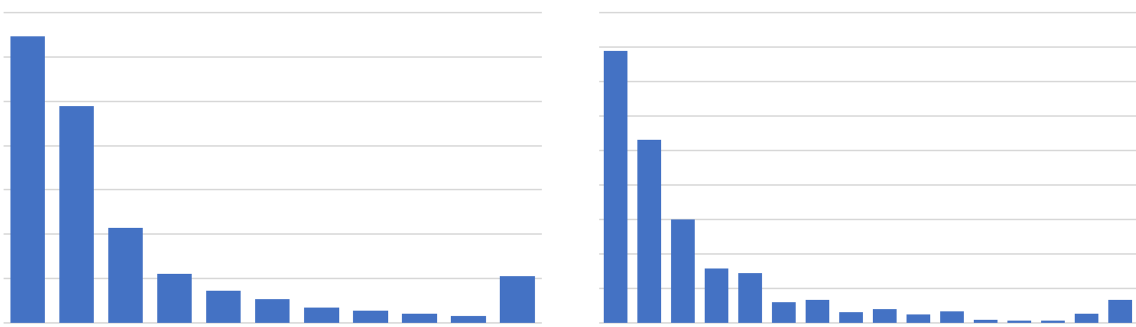


Figure 9: Frequency histogram of Amazon package's weight (left) and volume (right) since 2019

(Disclaimer: Data has been modified as noted in Page 7.)

To understand the correlation between package weight and package volume, we also made a weight vs volume plot representing X thousand packages from trips 1 to 6 from Table 5. The plot resulted in R-squared value of 0.55, which shows that these two variables do not have strong correlation (Figure 10).

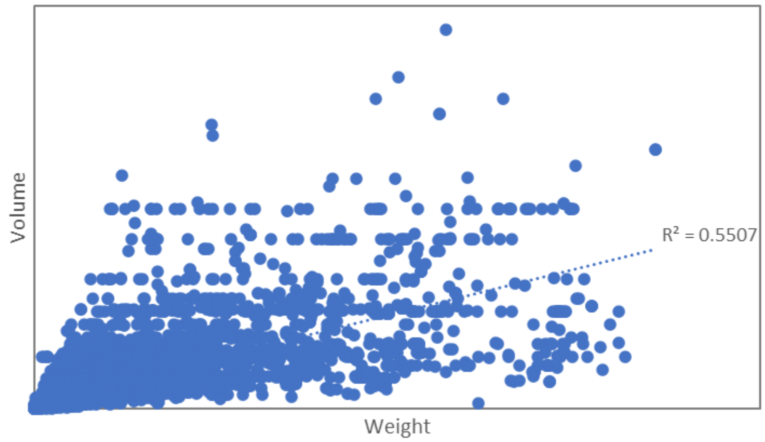


Figure 10: Package weight - volume plot

There were two main takeaways from this exercise; (1) the distribution looks similar in both weight and volume but does not show a strong correlation, and (2) more than 50% of the packages were "light" (less than 1 lb.) and/or "small" (less than 0.2 cft).

6.2 Carbon allocation visualization per logic

We tested four different carbon allocation logics ("per package", "per item", "per weight", and "per volume") on 20 MM/LM trips, as summarized in Table *5* and used box/violin plots to visualize the distribution.   We use trip #3's result to explain the general trend that was observed in other trips. Plots for all 20 trips can be seen in Appendix 2.

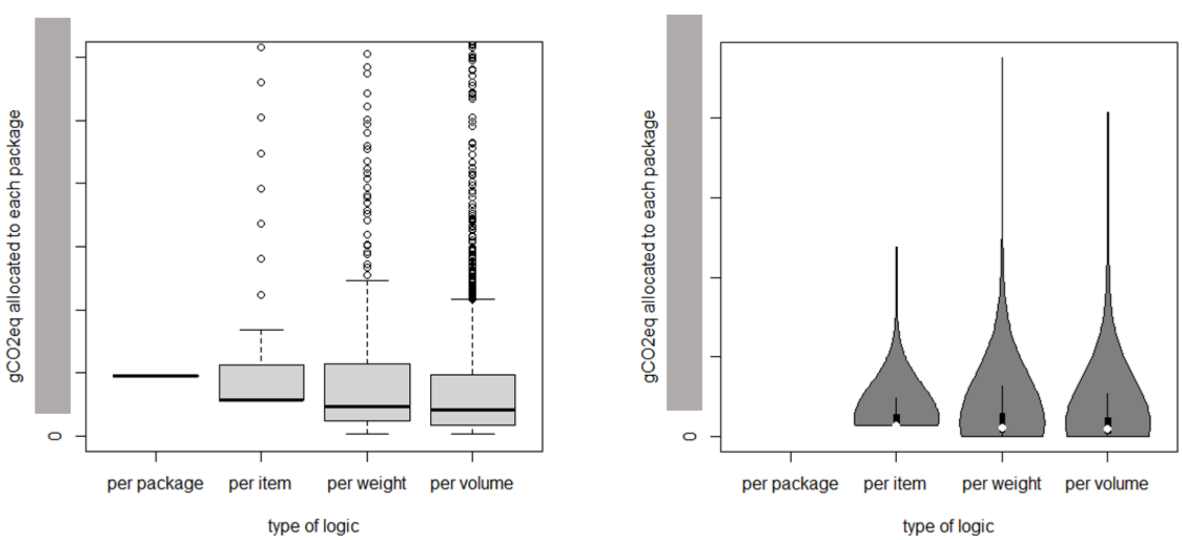


Figure 11: Box plot (left) and violin plot (right), trip #3

As seen in Figure 11, variability of GHG emission allocated to each package increased when item count, weight, or volume was used as denominator for calculating CI unit, instead of package count. In "per package" logic, all packages are allocated the same amount of carbon footprint, no matter how big or heavy a package was relative to other packages. This can be seen in the box plot in Figure *11*, represented as a single line without any spread. Since some packages contained more than 1 item, "per item" logic showed increase in variability compared to "per package" logic. The spread increased further when using "per weight" and "per volume" logics.

After observing the plots in Figure 11 and Appendix 2, we noticed how the median of each distribution decreased in "per item", "per weight", and "per volume" logics compared to "per package" logic. On average, median in "per item" logic decreased by 27.4% from "per package" logic, whereas median in both "per weight" and "per volume" logics decreased by approximately 50% (see Table 6).

Trip #	Region	Trip type	Difference compared to Per Package logic		
			Per Item	Per Weight	Per Volume
1	US	MM	-35%	-53%	-29%
2	US	MM	-10%	-27%	-34%
3	US	MM	-41%	-57%	-52%
4	US	MM	-10%	-37%	-29%
5	US	MM	-39%	-65%	-67%
6	US	MM	-32%	-50%	-50%
7	UK	MM	-32%	-55%	-58%
8	UK	MM	-32%	-58%	-71%
9	UK	MM	0%	-35%	-24%
10	UK	MM	-8%	-40%	-54%
11	DE	MM	-22%	-42%	-55%
12	DE	MM	-34%	-48%	-51%
13	DE	MM	-13%	-25%	-17%
14	DE	MM	-38%	-34%	-56%
15	US	LM	-28%	-66%	-60%
16	US	LM	-33%	-62%	-57%
17	US	LM	-39%	-66%	-64%
18	US	LM	-33%	-68%	-60%
19	US	LM	-25%	-56%	-53%
20	US	LM	-46%	-61%	-57%
Average			**-27.4%**	**-50.2%**	**-49.8%**

Table 6: Comparison of median in different carbon allocation logics

6.3 Discussion: "Per weight" or "per volume" logic?

From Figure 11 and Appendix 2, it can be said that using "per weight" and/or "per volume" logics to allocate GHG emission reflects the physical characteristic of each package more accurately in carbon accounting, and that those logics should be prioritized over "per package" and "per item" logics, since it will allow a fairer way of distributing accountability among business teams. However, both "per weight" and "per volume" logics showed similar carbon allocation distribution when plotted. This is not so surprising, given how similar the frequency distribution of package volume and weight was in Figure 9.

In order to decide how and when to utilize "per weight" or "per volume" carbon allocation logic, we first analyzed potential positive and negative consequences that each logic could have on Amazon's decarbonization goals, using causal loop diagrams. Causal loops diagram (CLD) is a tool to describe the feedback structure of a system. It is useful especially for understanding the potential positive/negative consequences of introducing a new system to an organization. We use CLD here to understand the effect of introducing "per volume" or "per weight" logics to Amazon's transportation business teams to track their decarbonization KPI and allocate carbon to interdependent teams.

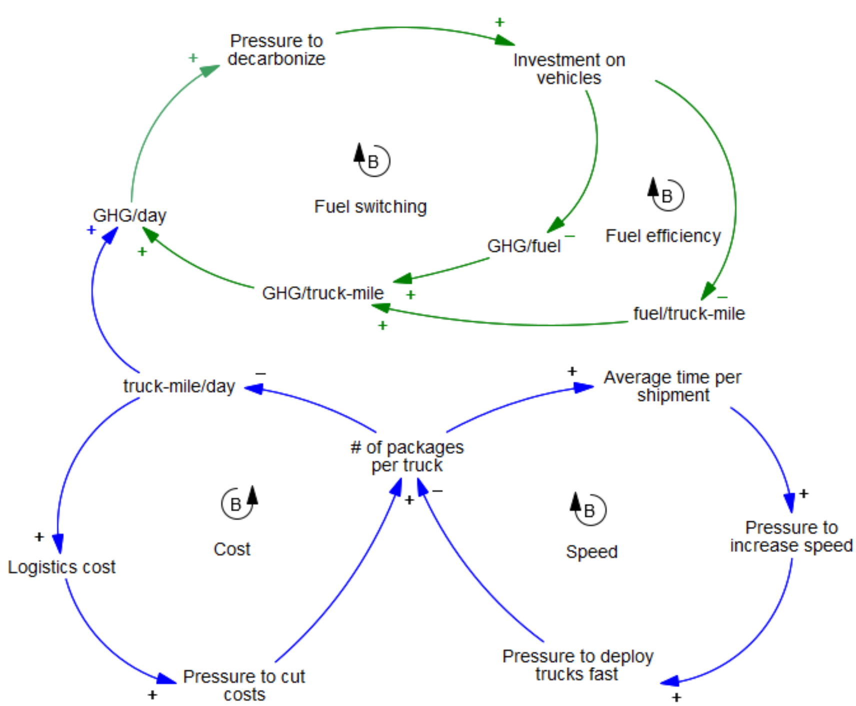


Figure 12: Causal loop diagram (cost and speed)

Figure 12 is a simple CLD which shows how prioritizing logistics cost reduction and increase in speed influences daily GHG emission from transportation. The model in blue shows that optimizing for cost and speed only does not address the problem of GHG emission, and there needs to be additional loops to drive decarbonization. Balancing loops in green in Figure 12 depict one of decarbonization efforts that Amazon is already working on (e.g., switching to EV vehicles and improving fuel efficiency), and how those efforts help decarbonize daily GHG emission from transportation. We assume this CLD as starting point and see how adding “per volume” logic as business KPI could change the behavior of the system.

If we introduce “per volume” logic to allocate carbon and track business KPIs, there are 2 possible way it could cause behavioral changes among Amazon’s transportation teams. First, the teams will be more willing to load as much as possible on a truck to decrease empty space, because reducing empty space will decrease CI of the trip (GHG emission/volume). This behavioral change is good for driving overall decarbonization in transportation, as it will help not only to decrease GHG emission/volume of each trip, but also to reduce the number of trucks that Amazon uses every day. This can be described as a balancing loop shown in red in Figure 13.

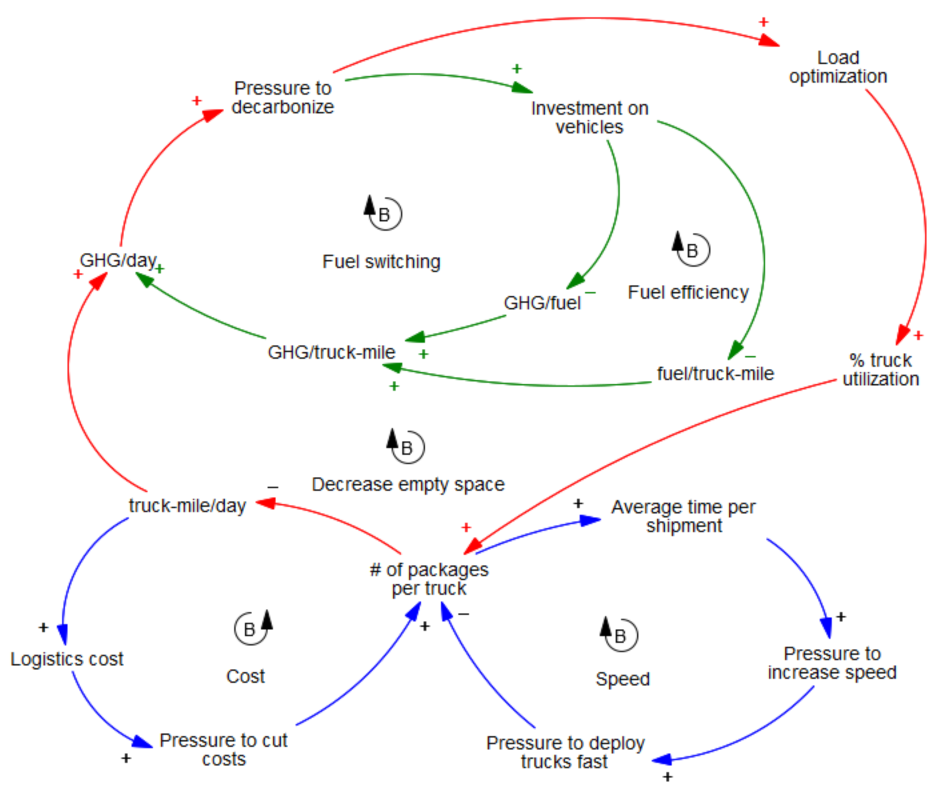


Figure 13: Causal loop diagram (decrease empty space)

Second, if “per volume” logic is used, then business teams will think of ways to reduce packaging materials so that their packages will take up less space and hold less accountability of carbon. This behavioral change could also allow more space on the truck to load other packages that would lower the trip’s overall GHG emission/volume (see orange balancing loop in Figure 14). However, on the flip side, if packaging reduction does not happen either at the same time or after making the effort to load more packages on each truck, it could unintentionally increase empty space, and as a result, increase GHG emission/volume of the trip (see orange reinforcing loop in Figure 14). It is only when both efforts happen at the same time that we can start to see improvements in both GHG emission/volume and overall GHG emission from transportation.

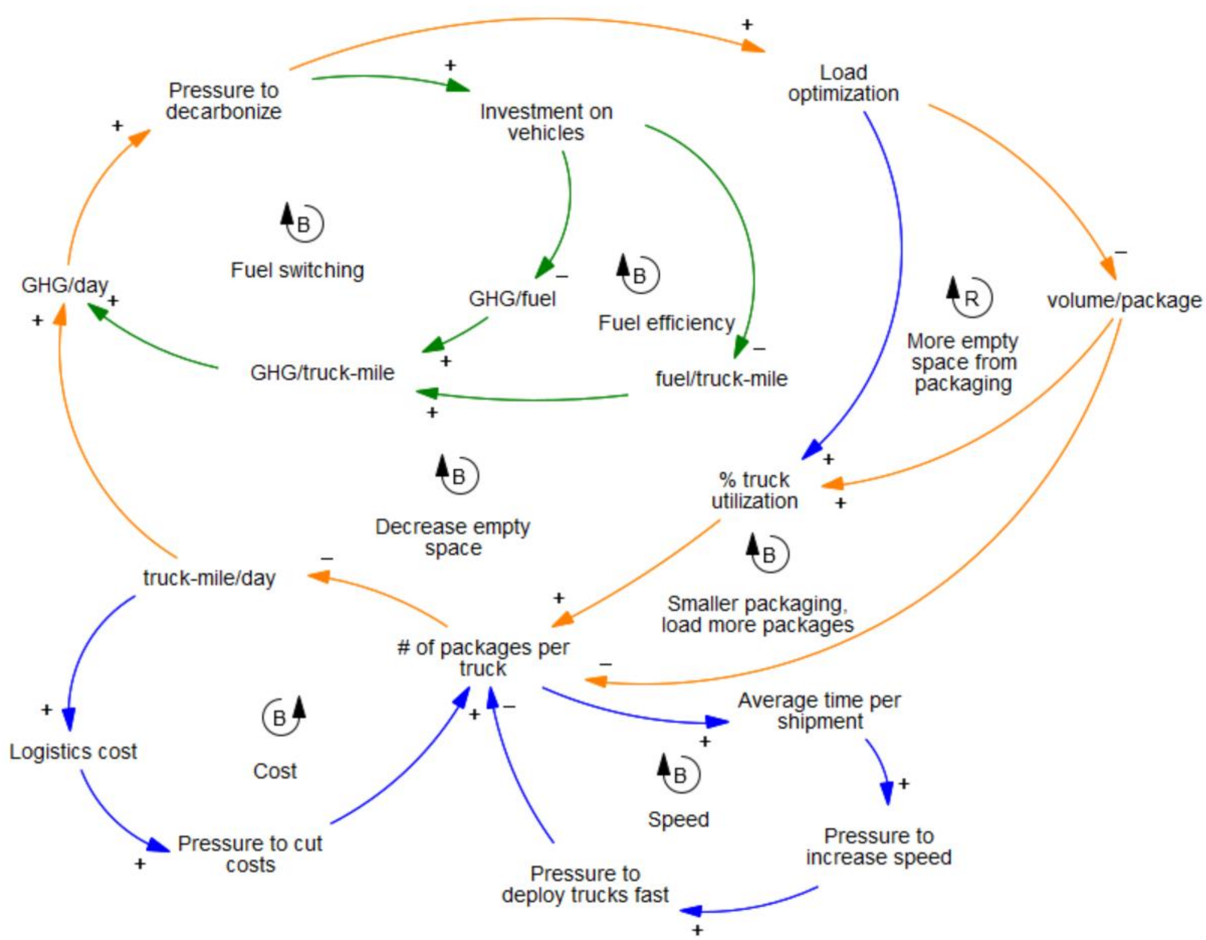


Figure 14: Causal loop diagram (Packaging)

In case "per weight" logic is used for allocating GHG emission, similar arguments could be made as "per volume" logic mentioned above. However, the main difference is that total weight of packages on a typical Amazon delivery truck is significantly lower than a truck's weight capacity, whereas it is easier for packages to reach volume capacity limit of the vehicle, due to the nature of Amazon's typical delivery packages (weight of packages <<< weight capacity of truck). Also, it is difficult to reduce the weight of packages, since Amazon does not have control over how much each product made by external manufactures weighs. This means that it may be difficult to drive behavioral change when using "per weight" logic compared to "per volume" logic.

In addition to above discussion on potential positive and negative consequences each logic could have on Amazon's transportation teams, data availability could be a potential bottleneck. For example, not all trips may have activity data on package-level weight and/or volume, especially for trips done by 3rd parties.

Since the purpose of this project is to build a carbon allocation methodology that companies can use as centralized method to hold internal businesses accountable for all trips, ideally, the methodology should be flexible and be able to apply to multiple different situations. Taking this into account, we propose a decision-tree mechanism for trips that were shared among multiple business teams, which depends on data availability (Figure 15). We prioritized volume-based logic over weight-based logic, due to its potential effect on overall decarbonization, as discussed using CLDs.

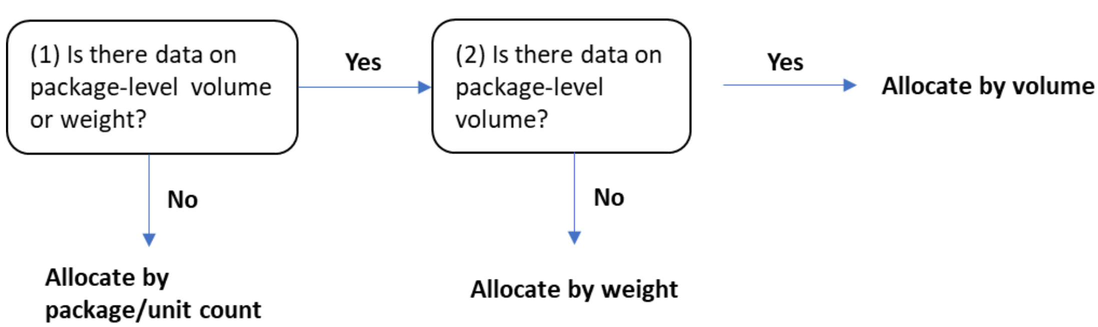


Figure 15: Decision tree diagram for carbon allocation logic in transportation

Similar concept could be applied to non-transportation businesses at Amazon, e.g., buildings and web servers. There is a need for carbon allocation methodology in non-transportation businesses as well, since multiple internal business teams utilize their assets for every day operation. For example, GHG emission from operating Amazon's corporate buildings can be allocated to business teams that utilize the building space. For this allocation, they could consider testing different logics similar to what we did for transportation teams, but by using different variables as denominator for CI calculation, e.g., head count of each team, number of desks used by each team, surface area occupied by each team.

Chap 7: Conclusion and Recommendation

7.1 Summary and Conclusion

In this project, we explored the different logics a company in transportation could use to allocate carbon footprint internally to its business teams with interdependencies, using activity data from Amazon's 20 trips as an example. We found that due to wide variety of volume and weight of packages, distribution of GHG emission allocated to each package widened when using "per weight" and "per volume" logics compared to "per package" logic. We also looked at potential positive and negative consequences from using weight and/or volume-based GHG emission KPIs using CLDs (Figures 13 and 14), which showed that although transportation teams will take action to decrease carbon intensity with best intensions, it could potentially drive negative consequences if not planned carefully.

Quality of activity data is also another bottleneck. With these observations in mind, we proposed a flexible carbon allocation mechanism whereby business teams will choose a logic depending on data availability (Figure 15). By having such mechanism that is both flexible and simple, we believe that it will allow transportation teams to adapt quickly and have a standardized method for allocating GHG emission from activities with multiple business teams. Also, it will allow each business team to understand its own contribution to Amazon's GHG emission and be empowered to decarbonize.

7.2 Future Recommendation

To continue and expand this project, we recommend taking below actions items.

1. Test the same logics using activity data from more trips. In this project, we tested the logics on 20 MM and LM trips only, which may not represent all the Amazon trips. We also suggest using data from first mile (FM), which was not possible at the time of this internship.
2. Collect package-level business team data, and run a business team-level carbon allocation test. (At the time of this project, business team data was not available due to confidentiality reasons.)

3. Collect package-level distance travelled data, and test “per distance” logic. (This data was not available at the time of this project.)
4. Expand the methodology to non-transportation teams, e.g., buildings, servers. To do so, we recommend diving deep into variables that could be used as denominator in measuring carbon intensity for each case, similar to package/item count, volume, weight in transportation. For example, building teams could consider head count (or number of desks used) per business team, or amount of floor area used by each team to allocate GHG emission from operating corporate buildings to users.

Appendix

Appendix 1: Greenhouse Gas

Greenhouse Gas (GHG) is a mixture of multiple types of gases, mainly carbon dioxide, methane, and nitrous oxide, which covers 98% combined of total GHG emissions, as of 2014[1,26]. These gases have the ability to trap heat in the atmosphere, which exhibits greenhouse effect.

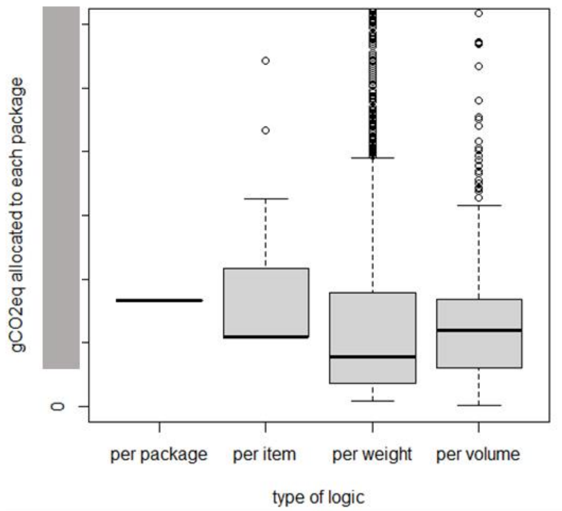
According to IPCC report in 2014, CO_2 accounted for 76% of global greenhouse gas emissions (Figure X)[26]. Although it exists naturally in the atmosphere, amount of CO_2 increased significantly (20% increase in less than 40 years), due to human activities[20]. Emission of carbon dioxide (CO_2) is mainly contributed by industrial activities (e.g., fossil fuel combustion, cement manufacturing) and land use (e.g., mining)[1]. Below are three main sources of CO_2 emissions in the US;

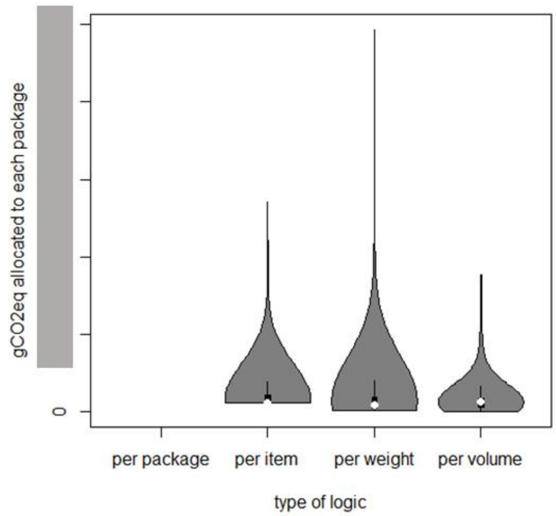
- **Transportation (35%)**: In 2019, combustion of fossil fuels (e.g., gasoline, diesel) used for transporting people and goods was the biggest contributor to CO2 emission in the US.
- **Electricity (31%)**: Fossil fuel is the main source for generating electricity.
- **Industrial processes (16%)**: many processes require fossil fuel for power, but several processes also emit CO_2 as byproduct (e.g., production of cement, metals, chemicals)

Appendix 2: Plots of Trips #1 - 20

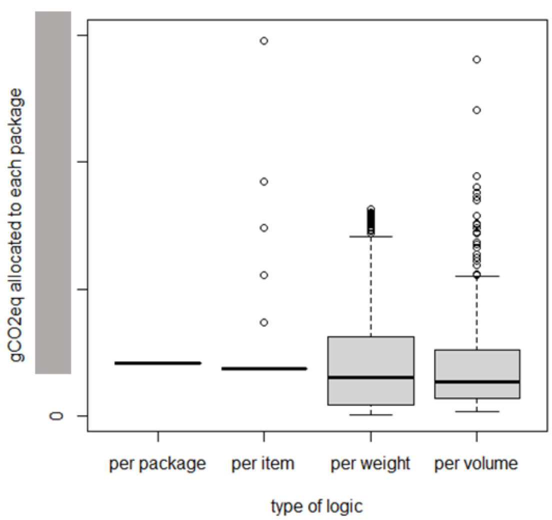
Below are box and violin plots of trips #1 – 20 (Table 5.2).

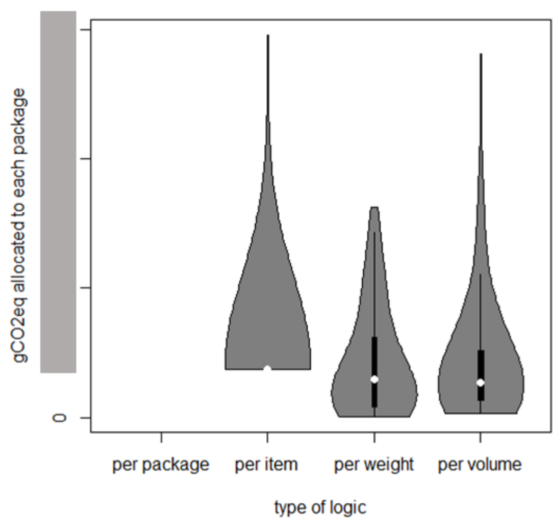
Trip #1 (NA MM)



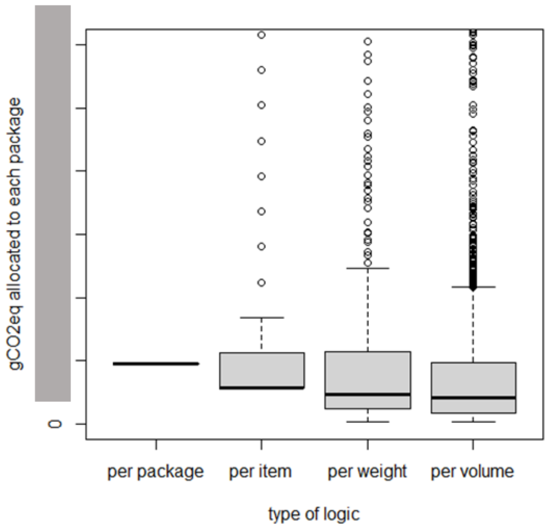


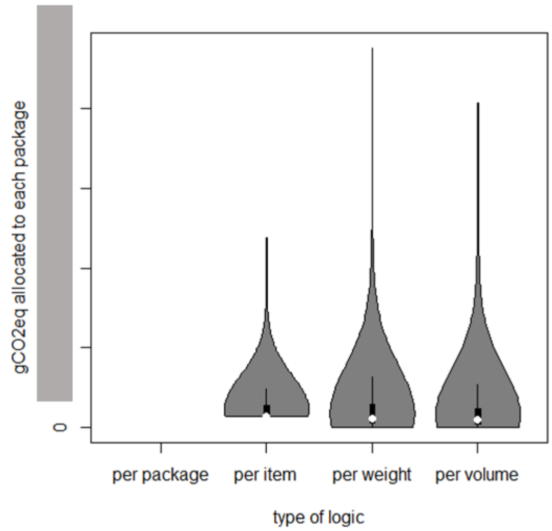
Trip #2 (NA MM)



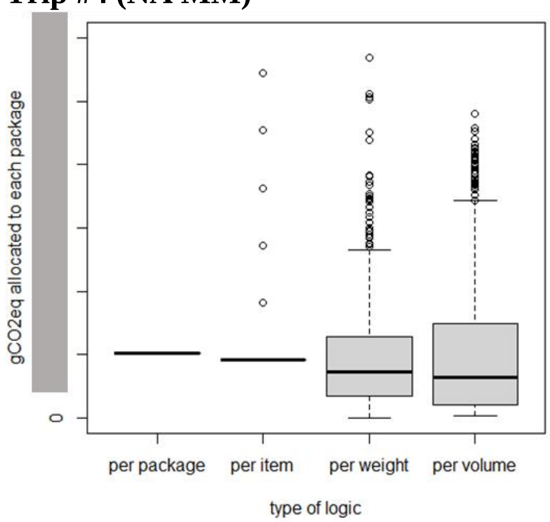


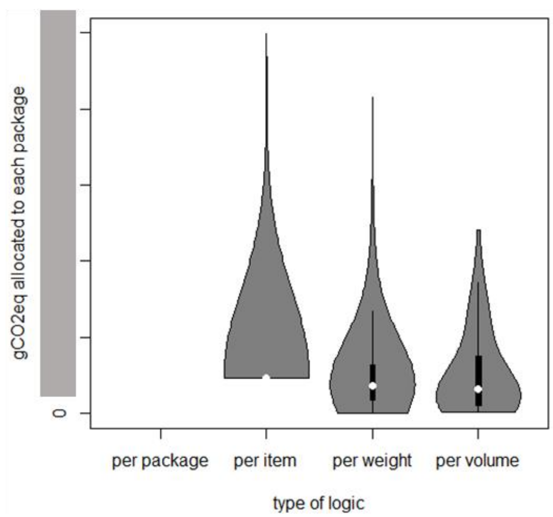
Trip #3 (NA MM)



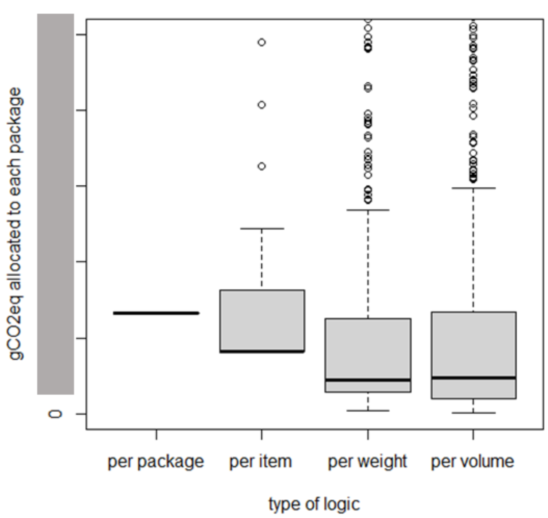


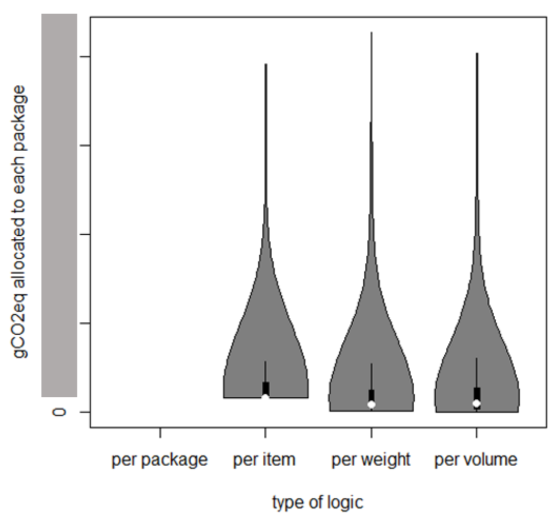
Trip #4 (NA MM)



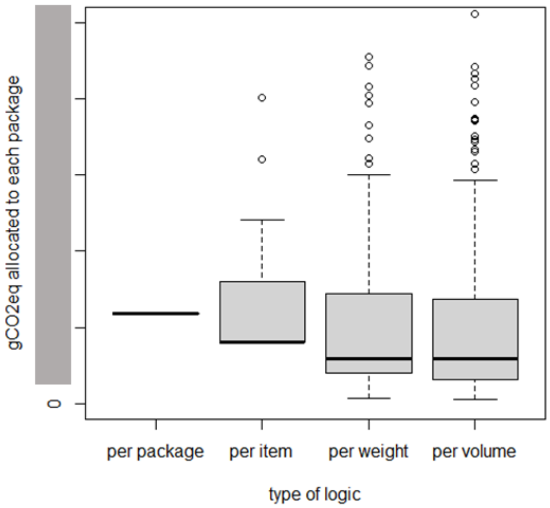


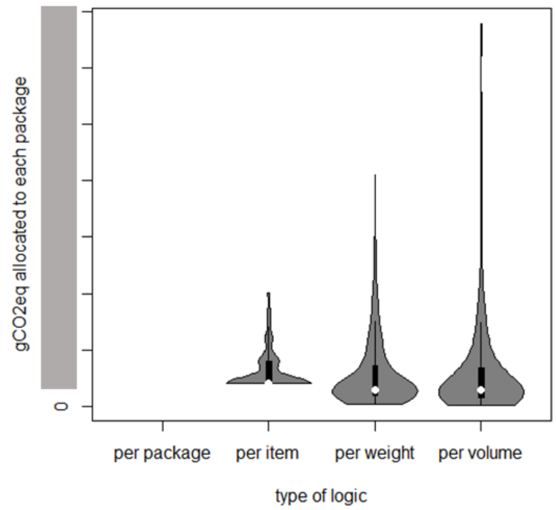
Trip #5 (NA MM)



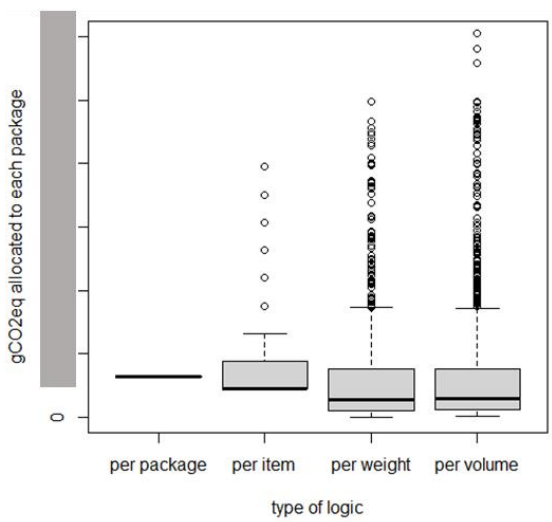


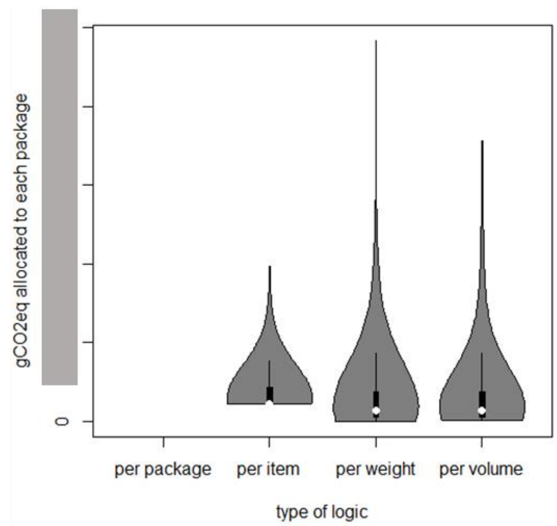
Trip #6 (NA MM)



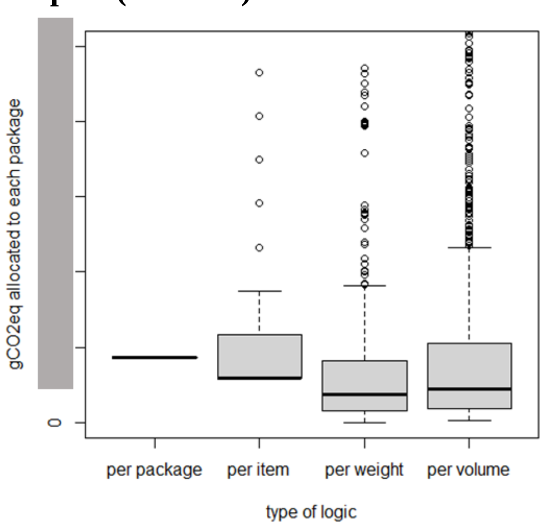


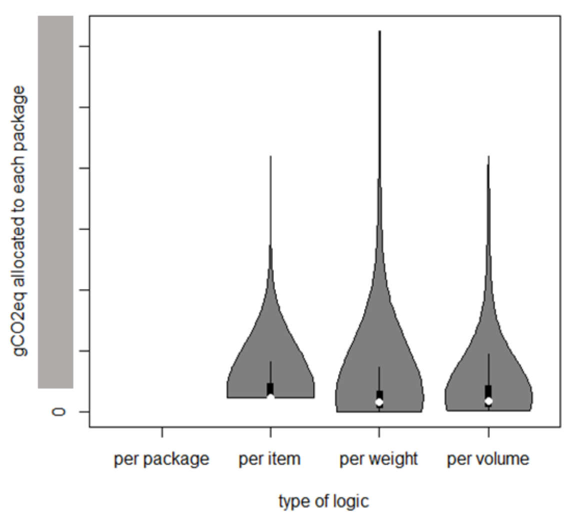
Trip #7 (GB MM)



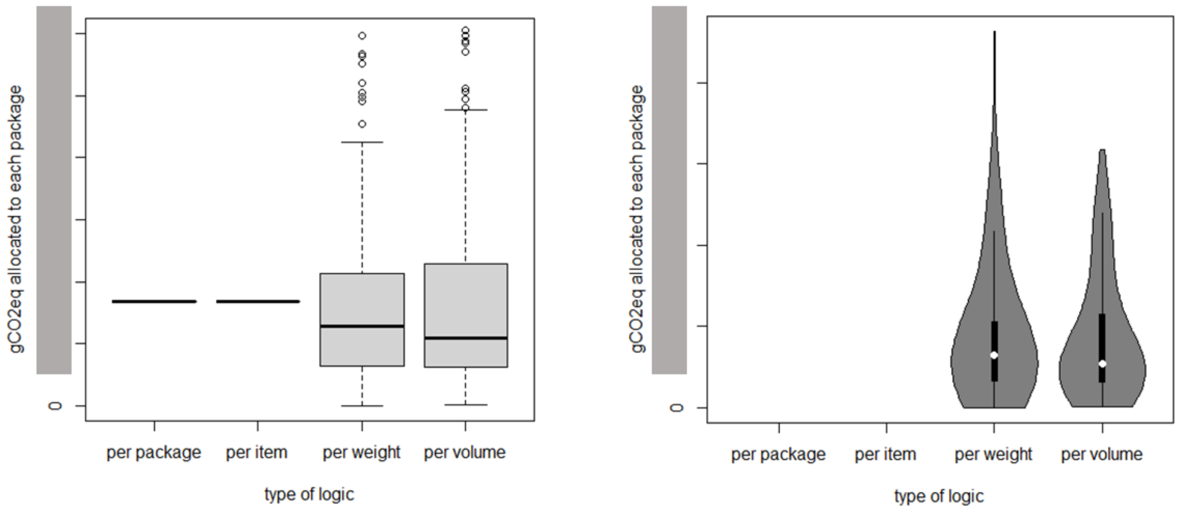


Trip #8 (GB MM)

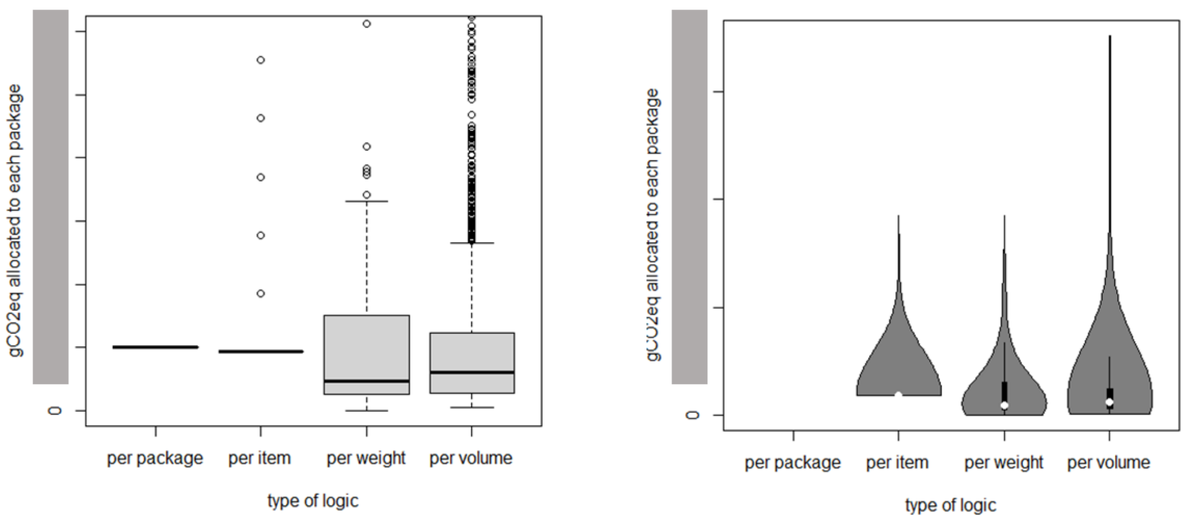




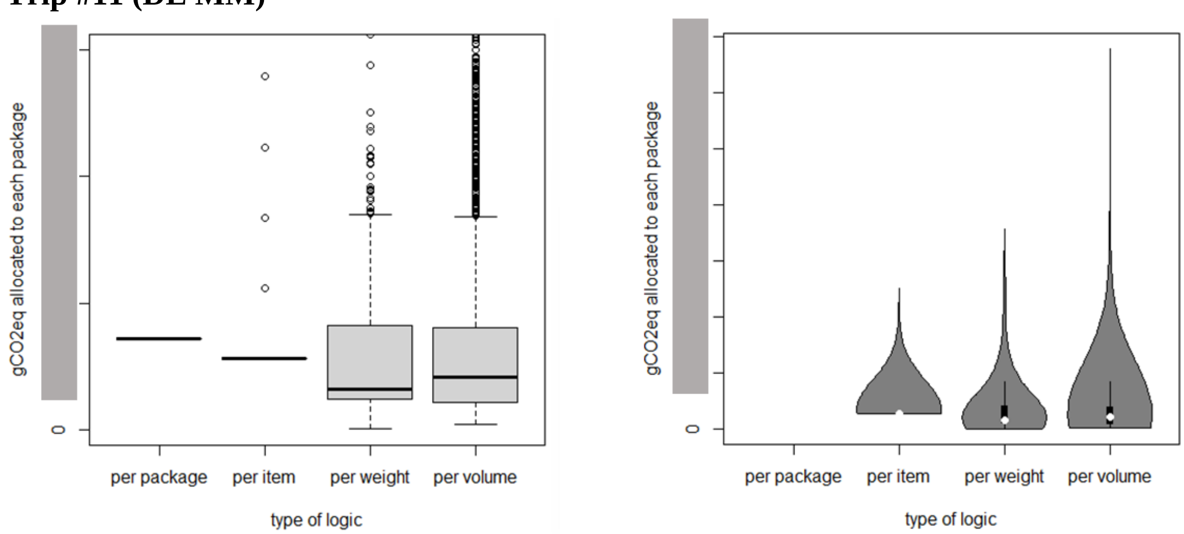
Trip #9 (GB MM)



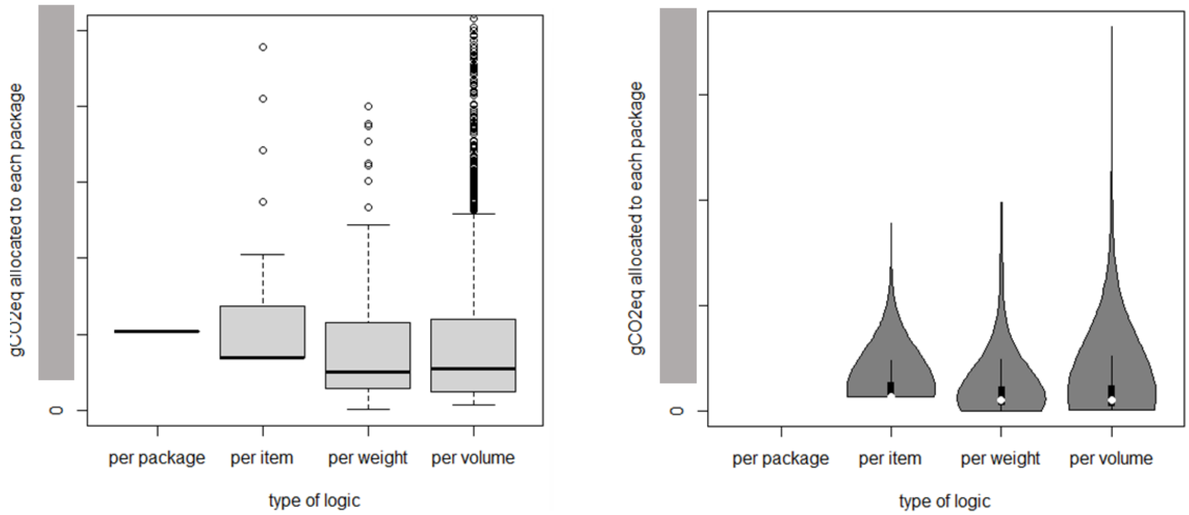
Trip #10 (GB MM)



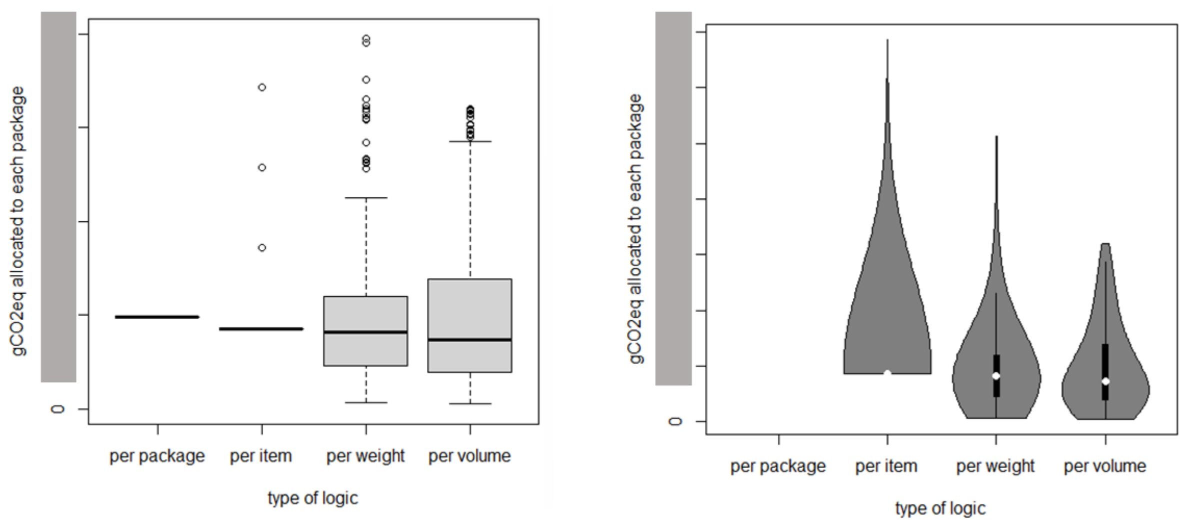
Trip #11 (DE MM)



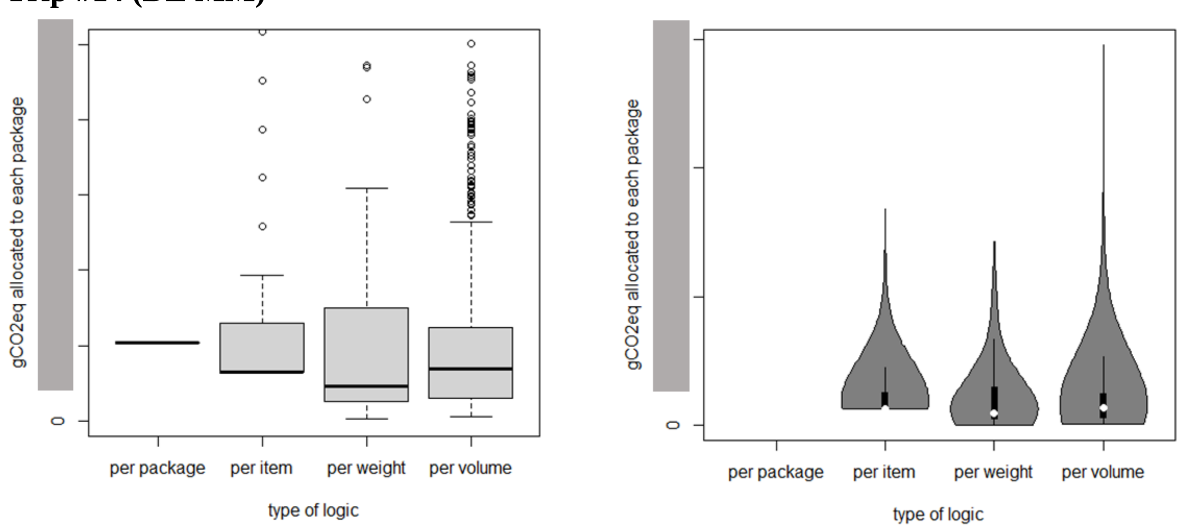
Trip #12 (DE MM)



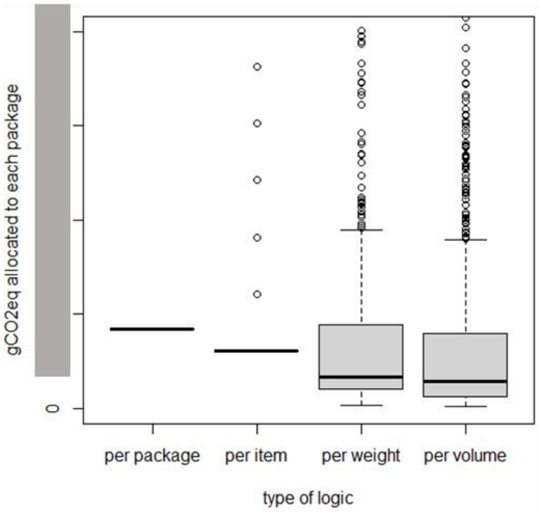
Trip #13 (DE MM)

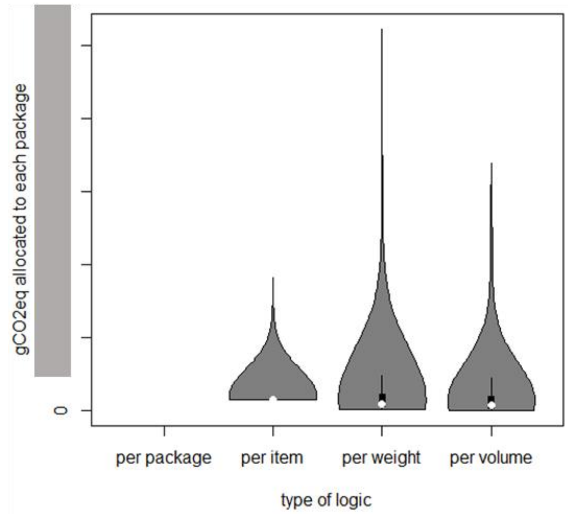


Trip #14 (DE MM)

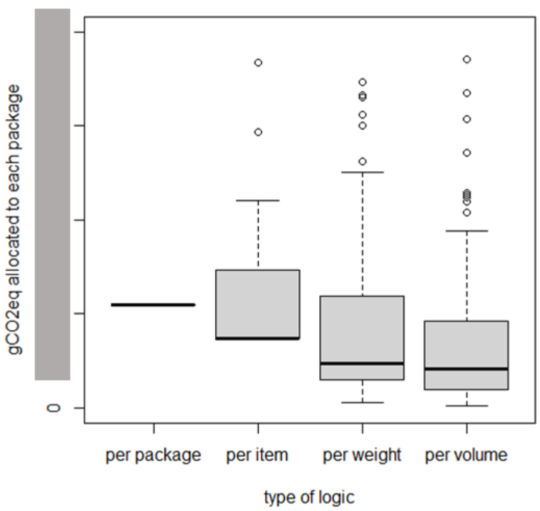


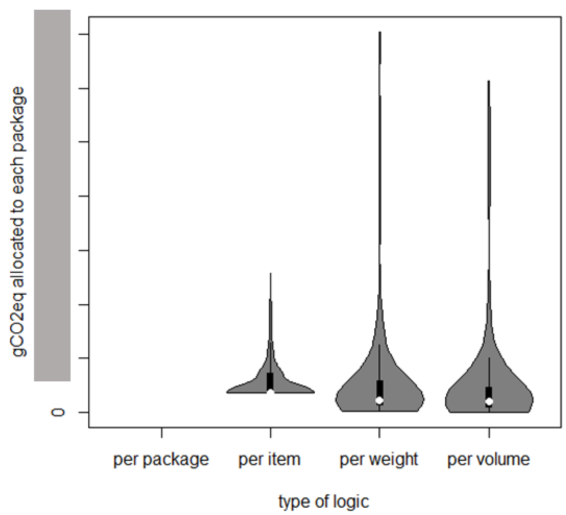
Trip #15 (NA LM)



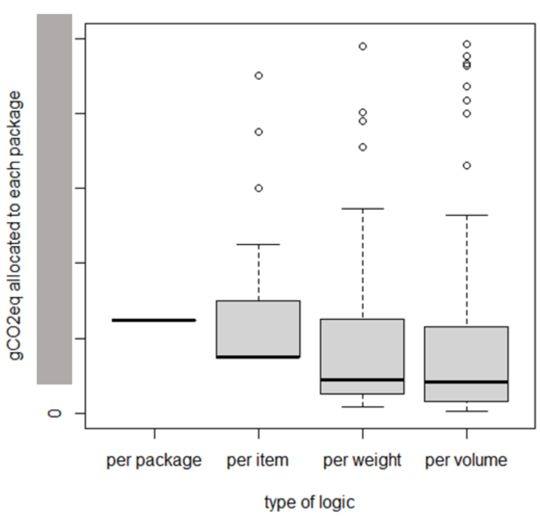


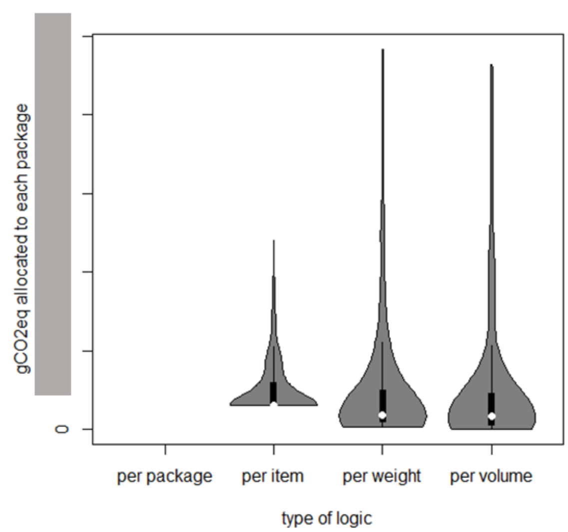
Trip #16 (NA LM)



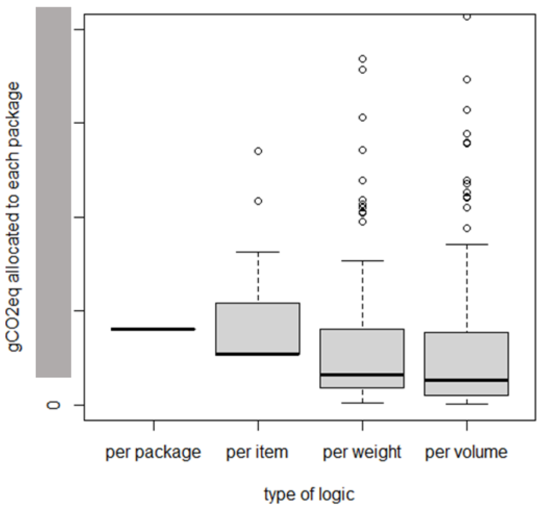


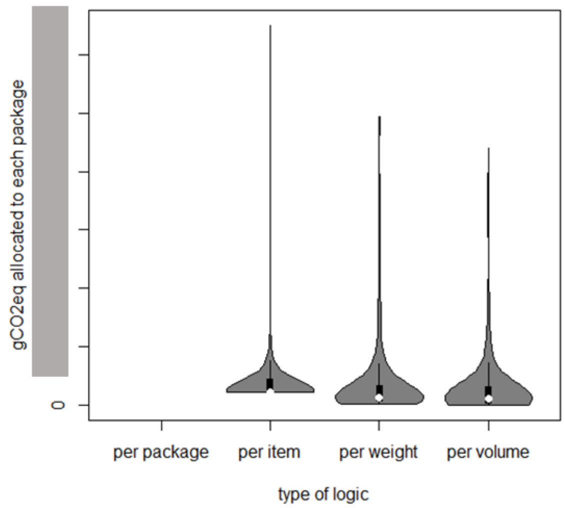
Trip #17 (NA LM)



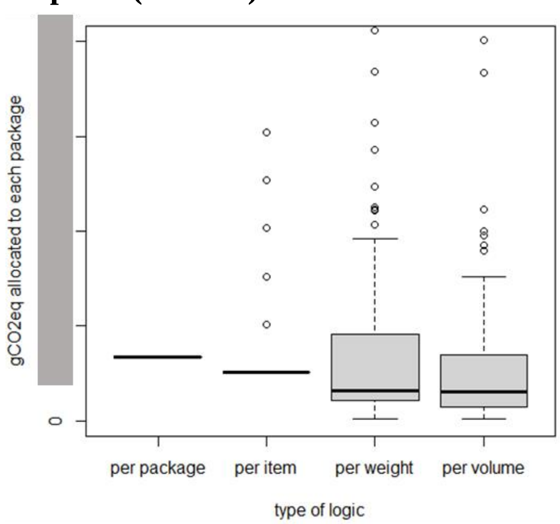


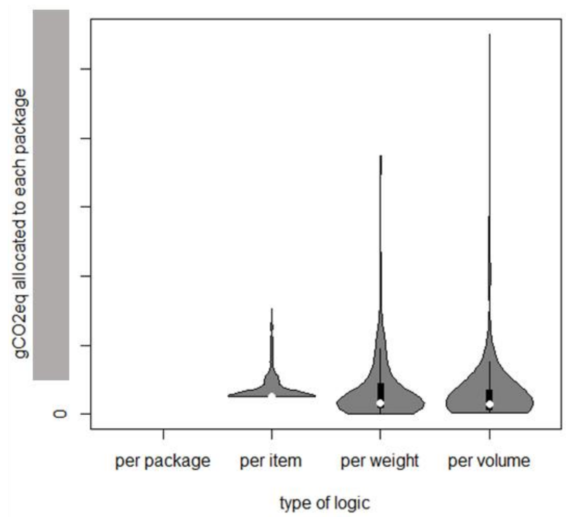
Trip #18 (NA LM)



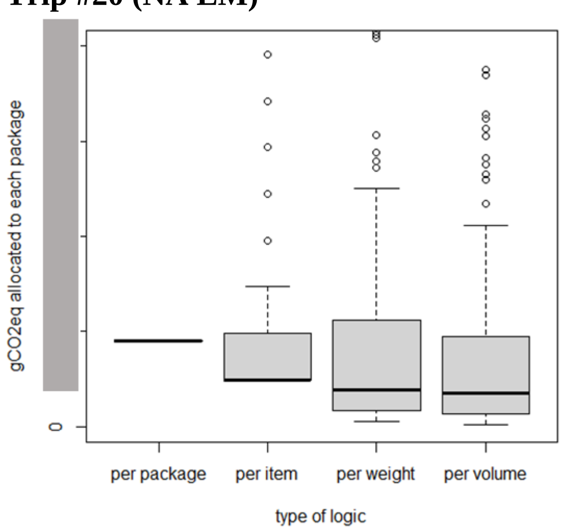


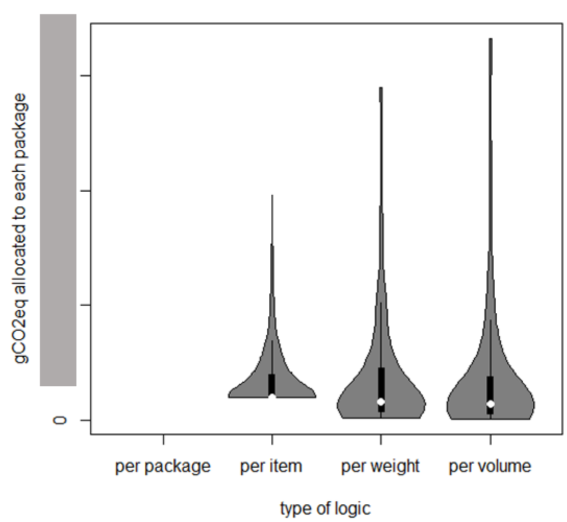
Trip #19 (NA LM)





Trip #20 (NA LM)





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