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Estimating CO_2 Emissions (CO_2e) from the Plastic Water Bottle Supply Chain: A Case Study

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Abstract

This study investigates the carbon footprint of the plastic water bottle supply chain in Kuwait through a case study of a local manufacturer producing over 50,000 bottles daily, representing nearly 20% of national production. The research applies a Life Cycle Assessment (LCA) framework combined with Activity-Based Costing (ABC) to quantify CO_2e emissions across the supply chain stages: **Buy** (raw material procurement), **Make** (manufacturing), and **Move** (logistics). Resource consumption—including PET material, electricity, fuel, and water—is converted into CO_2e using standardized emission factors. Results indicate total annual emissions of approximately **6,500 metric tons CO_2e**, with logistics operations accounting for 51% of emissions, electricity 30%, and PET materials 19%. Emissions vary substantially by bottle size; for a benchmark of 60 liters, 1.5 L bottles produce ~30 kg CO_2e, while 200 mL bottles generate ~81 kg CO_2e, demonstrating that smaller bottles are two to three times more carbon-intensive per liter. The findings highlight the dual responsibility of manufacturers and consumers in mitigating environmental impacts. Recommendations include **optimizing supply chain logistics, exploring alternative fuels, implementing last-mile micro-fulfillment centers, adjusting bottle sizes, and increasing consumer awareness through CO_2e labeling**. This study provides actionable managerial insights for SMEs and contributes to the literature on sustainable supply chain management in carbon-intensive regions.

Keywords: Sustainable Supply Chain, CO_2 Emissions, Bottled Water, Life Cycle Assessment, Activity-Based Costing, Kuwait, Last-Mile Logistics

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1. Introduction

Sustainability is a big deal for companies nowadays. They have to deal with a lot of pressure from the government and society to be kind, to the environment. Companies need to reduce the stuff they put into the air like carbon while still being able to run their business smoothly and make money. One of the problems companies face is climate change. Sustainability is a concern because climate change is happening and it is mostly caused by bad things people put into the air like carbon dioxide. Sustainability is important for companies to think about because they need to reduce their carbon footprint, which's the amount of carbon dioxide equivalent they put into the air. These emissions are now widely recognized not only as an environmental concern but also as a strategic risk that can influence organizational costs, regulatory exposure, brand reputation, and long-term resilience (Ahmad & Khattak, 2020).

When we look at management from a point of view we can see that people are now paying more attention to sustainability. This means that managers can not just think about making money and getting things done. They have to think about the environment. They have to consider the environment when they make plans control things and make decisions. Supply chains are a part of this change. The reason is that supply chains produce a lot of emissions, for organizations. This is because they need a lot of energy to make things they use a lot of materials. They have to transport things, which uses a lot of energy. Supply chains are really important because of this. They are a part of the problem. Consequently, sustainable supply chain management has gained prominence as a strategic capability that enables organizations to align environmental objectives with traditional performance goals such as cost efficiency, responsiveness, and service quality.

The moving consumer goods industries are really important here. They make a lot of products. They all look the same. They also have a system to get these products to people. The bottled water industry is an example of this. It uses a lot of bottles, trucks that run on fossil fuels to move the water and people all around the world want to buy more bottled water. The bottled water industry is a part of the fast-moving consumer

goods industries. Previous studies indicate that bottled water production generates a higher carbon footprint compared to tap water alternatives, largely due to the production of polyethylene terephthalate (PET) bottles and the emissions associated with transportation and distribution (Misopoulos et al., 2020; Souto-Martinez et al., 2018).

The research on Life Cycle Assessment of water shows that making PET bottles and getting them to stores are the main reasons for the high levels of CO_2e emissions. Transportation is a part of this and it is usually powered by diesel fuel. This can cause a lot of emissions especially when bottled water has to be sent to places that're really far away. Life Cycle Assessment research has found that transportation is a problem and this is true for bottled water that is sold in many different areas as seen in the work of Misopoulos and others in 2020. Life Cycle Assessment is important for understanding the impact of water, on the environment. These findings highlight the importance of viewing sustainability not only as a product-level issue but as a supply chain and managerial challenge that requires coordinated decision-making across sourcing, production, and distribution activities.

The bottled water supply chains are really bad for the environment. This is especially true in places where people drink a lot of water and the energy they use is not clean. Some countries like Kuwait have a problem with this. They are part of the Gulf Cooperation Council. They make a lot of carbon dioxide. This is because they use a lot of fuels and do things that use a lot of energy. People like Ahmad and others have written about this in 2021. Bottled water supply chains are bad for the environment so places like Kuwait need to be careful, about how they use energy. At the same time, bottled water consumption in these countries continues to grow as a result of factors such as perceptions of tap water quality, convenience, lifestyle preferences, and marketing strategies (Hidalgo-Crespo et al., 2022). This combination of high demand and carbon-intensive operations amplifies the environmental footprint of bottled water production and distribution.

For organizations operating in Kuwait, these conditions create a pressing need to adopt more sustainable supply chain practices while maintaining economic viability. Managers are increasingly required to quantify and understand the environmental consequences of their operational decisions in order to comply with emerging regulations, respond to stakeholder expectations, and identify opportunities for efficiency improvements. However, translating sustainability goals into actionable managerial strategies remains a challenge, particularly when environmental assessments are not directly linked to operational data or decision variables.

Life Cycle Assessment methods are used a lot to see how things affect the environment.. Many studies use data that is combined from a lot of different places or they look at the whole process from start to finish which can be hard for managers to understand and use in real life as noted by Go and others in 2024.

Small and medium-sized enterprises, like bottled water manufacturers do not have a lot of people or knowledge to use complicated tools to check if they are being sustainable according to Bianco and others in 2024. Life Cycle Assessment methods are still really important for bottled water manufacturers to see how they affect the environment. From an administrative sciences viewpoint, there is therefore a clear need for simplified, transparent, and managerially relevant frameworks that connect carbon accounting with operational decision-making.

Furthermore, product-level characteristics—such as bottle size and packaging intensity—have received limited attention in managerial sustainability research, despite evidence that these factors significantly influence emissions per unit of consumption. Recent studies suggest that smaller bottle sizes can result in disproportionately higher CO_2e emissions due to increased material usage and transportation requirements (Panaksri et al., 2024). Understanding these relationships is essential for managers seeking to design product portfolios and distribution strategies that balance consumer preferences with environmental performance.

In light of these considerations, examining CO_2e emissions across bottled water supply chains using firm-level operational data offers valuable insights for both

theory and practice. By focusing on supply chain stages and product characteristics that managers can directly influence, such research contributes to bridging the gap between environmental assessment and administrative decision-making. This study responds to this need by providing an applied analysis of carbon emissions in a bottled water supply chain, grounded in real operational data from a Kuwaiti manufacturing context.

The demand for water all around the world has gone up a lot in the last few decades. It is growing three times faster than other things we drink. Mexico is the place where people drink the bottled water. They drank 64.5 gallons of water per person in 2018. The United States comes next where people drank 36.5 gallons of water per person. Then there is Hong Kong, where people drank 29.6 gallons of water per person. Bottled water demand is really high in these places. The demand, for water is still going up. In Europe, Italy reported 188.5 liters per person in 2016, well above the regional average of 110 liters (Misopoulos et al., 2020).

The growth of water is happening really fast and it is because of many things. People do not think tap water is safe they do not like the taste or smell of it companies are good at selling water and it is easy to buy bottled water. Bottled water is bad for the environment. Making plastic bottles moving them around and getting rid of them makes a lot of things go into the air uses up resources and makes a lot of trash that hurts the earth. Bottled water is a problem because of this. Bottled water companies like Hidalgo-Crespo and others have said this in 2022. Other people, like Rosner and Pölz and Souto-Martinez have also talked about the problems of water in 2024 and 2018. In regions with limited recycling infrastructure, such as parts of the Middle East, these effects are amplified (Panaksri et al., 2024).

Sustainability is a deal for companies that produce bottled water. It is very important for medium-sized businesses to think about this. These businesses often do not have the tools to figure out where they are producing a lot of carbon. This is a problem because they need to know where they are going wrong so they can make changes. Companies that produce water need simple ways to measure the bad things they are

doing to the environment so they can make good decisions about how to do things better. Sustainability, in bottled water production is something that companies really need to focus on. Life Cycle Assessment (LCA), combined with Activity-Based Costing (ABC), provides a framework for such analysis by linking resource usage to specific supply chain activities and product lines (Go et al., 2024; AlDhaheri, 2022).

This study focuses on the plastic water bottle supply chain in Kuwait, examining emissions across the Buy, Make, and Move stages. The research aims to:

1. Identify which supply chain stage contributes most to CO_2e emissions.

2. Compare emissions across different bottle sizes for a standard consumption volume.

3. Provide actionable recommendations to reduce the environmental footprint, including logistics optimization, product design, and consumer-focused interventions.

Given Kuwait's high per capita energy consumption and carbon intensity (Ahmad et al., 2021), understanding and mitigating emissions from bottled water production is not only environmentally important but also strategically relevant for SMEs aiming to remain competitive while adhering to sustainability expectations.

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2. Problem Statement

There is a lot of talk about carbon emissions. Making supply chains more sustainable.. There are still some big gaps in our knowledge. We need to look at companies and see how they are doing things. Especially when it comes to water in the Middle East like in Kuwait we do not have a lot of information about carbon emissions. We need studies that use real data from companies to figure out how much carbon emissions are coming from bottled water supply chains in Kuwait. Bottled water supply chains, in Kuwait are not well understood when it comes to carbon emissions. Much of the existing research relies on secondary datasets, generalized emission factors, or international benchmarks that may not accurately reflect local

production conditions, energy mixes, or logistics structures (Misopoulos et al., 2020; Go et al., 2024). This limits the relevance of such studies for managerial decision-making at the firm level.

Second when we look at research that has been done before it usually looks at carbon emissions as a whole for a company or industry. It does not break down where the emissions are coming from like which part of the supply chain they are from. This makes it hard for managers to figure out which parts of the supply chain, like getting materials making things or moving things from one place to another are making the carbon emissions. Without this level of detail, it becomes difficult for decision-makers to prioritize interventions, evaluate trade-offs, or assess the effectiveness of sustainability initiatives (Khattak et al., 2020).

Third, product-level characteristics, particularly packaging size and design, remain underexplored in emission analyses within bottled water supply chains. Emerging evidence suggests that smaller bottle sizes can generate disproportionately higher emissions per unit of consumption due to increased material usage, packaging intensity, and transportation frequency (Panaksri et al., 2024). However, few studies have systematically examined this issue using product-level carbon accounting frameworks that are directly linked to managerial decisions regarding product mix, packaging strategy, and distribution planning.

In addition, many existing sustainability studies focus primarily on environmental outcomes while giving limited attention to their managerial and decision-making implications. From an administrative sciences perspective, sustainability assessments should not only quantify emissions but also provide insights that support planning, control, and strategic decision-making. The absence of applied frameworks that translate environmental data into managerial insights represents a significant gap in the literature, particularly for organizations operating in carbon-intensive regions.

Accordingly, the core problem addressed by this study is the lack of a clear, operational, and managerially relevant framework for estimating and analyzing CO_2e emissions across bottled water supply chains in Kuwait. There is a need for an

applied approach that integrates supply chain analysis with carbon accounting, disaggregates emissions across key operational stages, and links environmental outcomes to product characteristics and managerial decision variables. Addressing this gap can support managers and policymakers in designing more effective strategies to reduce emissions while maintaining operational efficiency and meeting growing consumer demand.

3. Literature Review

3.1 Sustainability in Supply Chain Management

Sustainable Supply Chain Management is a deal these days. People who study business and people who run companies are all talking about Sustainable Supply Chain Management. This is because companies are feeling a lot of pressure to make money protect the environment and be good to people at the time.

Sustainable Supply Chain Management is about making sure that we think about the environment and society when we make decisions, about how to get things make things move things around and get rid of things when they are no longer needed. According to Dubey and other people who have written about Sustainable Supply Chain Management In the year 2020 companies that use Supply Chain Management frameworks do a lot of good things. They make the environment better. They also get ahead of their competitors. This happens because they are able to reduce costs. They also avoid getting in trouble with the government.. They make their brand look really good to people. Sustainable Supply Chain Management frameworks are really helpful, to companies. Companies that use Supply Chain Management frameworks can reduce costs and make people think their brand is great.

When we talk about industries that use a lot of carbon, Sustainable Supply Chain Management is really important. The way things are made moved around. Packaged are the main things that cause carbon emissions. For products, like bottled water these parts of the process are what hurt the environment the most. Some people did a study. Found this out (Misopoulos and others 2020). If we want to make a difference

we need to look really closely at each part of the supply chain as other people have also said (Khattak and others 2020; Go and others, 2024). This will help us figure out what changes will make the impact.

3.2 Life Cycle Assessment (LCA) in Bottled Water Production

Life Cycle Assessment is a way to figure out how things affect the environment. It looks at the life of a product from when the materials are first taken out of the ground to when it is thrown away. This includes getting the materials making the product moving it around using it and getting rid of it at the end. Life Cycle Assessment is used for products for making things and for getting things from one place to another. The people who make the rules for this like the ones at ISO 14040 in 2020 call it the life cycle from start, to finish. Life Cycle Assessment is important because it helps us understand how products and supply chains affect the environment.

When we look at the life cycle of water we see that making bottles from PET and getting them to stores are big reasons for carbon emissions. For instance some researchers like Misopoulos and his team found out in 2020 that making PET bottles is responsible for 60 percent of the total carbon emissions from bottled water. On top of that transporting the bottles adds another 25 to 30 percent to the emissions. Other researchers, such as Souto-Martinez and his team pointed out in 2018 that bottled water plants use a lot of energy and that shipping water over long distances makes carbon emissions even worse, especially in places that rely heavily on fossil fuels, like coal and oil.

Recent life cycle assessment studies also point out that the location really matters. Ahmad and his team found out in 2021 that the amount of carbon used varies a lot from one country to another. This is because countries use kinds of energy have different ways of transporting things and their industries work at different levels of efficiency. This shows how important it is to have information, about each company and each location in order to really know how sustainable something is. Many studies that look at the world at once do not pay attention to this.

3.3 Product-Level Factors Affecting Carbon Emissions

New studies are showing that the things that make up a product like how big the bottle's what the packaging looks like have a big impact on how much CO_2e is released when we use it. Panaksri et al. Found out in 2024 that smaller bottles usually lead to a lot emissions for each thing we use and this is because of things, like:

• Increased material usage per liter of water.

• Higher packaging intensity and manufacturing energy.

• We need to move water around often for the amount of water that is actually delivered. This means we have to increase the number of times we transport water. The transportation of water has to happen frequently when we are delivering a certain amount of water.

The other people he worked with found out in 2024 that making things lighter like using less PET or making the bottle shape better can cut down carbon emissions by up to 15 percent. This is good because it does not affect what the people who buy these things think of them. Bianco and the other people he worked with said that reducing the thickness of PET or optimizing the bottle shape are strategies, for lightweighting. These lightweighting strategies can help reduce carbon emissions from Bianco and the other people he worked withs products.

Managers can make their companies better by changing the way they design and distribute products. They should think about how to make things cheaper and easier for people to get but about how to help the environment. So managers need to use information about the effects of each product when they make decisions. This will help them make sure that their business goals are good, for the environment too. They need to use product level information to make decisions and make their companies more sustainable.

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3.4 Bottled Water Supply Chains in Carbon-Intensive Regions

In areas where people use a lot of energy and produce a lot of CO_2e per person like the GCC, the bad impact of water on the environment is really big. Ahmad and others found out in 2021 that Kuwait and the countries around it are among the worst in the world for emissions per person. This is mostly because they get their electricity from fuels and have a lot of industrial activities. When you add the fact that people want to buy bottled water it makes the emissions from the whole supply chain of bottled water really high. The environmental footprint of water is a major problem, in these places and the supply chain emissions of bottled water are very significant.

The people who wrote the study, Hidalgo-Crespo and others said in 2022 that what people buy and use in areas how they behave when they buy things and the roads and buildings around them all have a big effect, on the carbon footprint of bottled water. For example:

• Urban areas where people live apart make it necessary for them to travel long distances to get from one place to another in these urban areas.

• People really like to buy bottles but this means that companies have to make more packaging and transport these bottles, which is bad for the environment because it increases the emissions, from packaging and transport of small bottles.

• Using diesel-powered trucks to deliver things makes the problem of carbon emissions from companies, like Reliance even worse.

These insights show us that we really need to look at things in a context. Using benchmarks from around the world or combining data from lots of places can give us the wrong idea about emissions. This can lead to managers making decisions, about the company. We need to make sure we are looking at the specifics of our situation when we are trying to figure out what to do about emissions.

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3.5 Methodological Gaps in Existing Research

There are still some problems, with the way things are being done even though a lot of research is being published. Several methodological gaps remain in the literature on the subject of gaps. The literature has a lot of information. It still has some methodological gaps.

1. The use of industry data that has been put together from lots of sources is a problem. Many studies use numbers for emissions or information that is not directly from the source. This makes it hard for companies to make decisions based on the information they get. For example some researchers like. His team found this out in their study that was done in 2024. The use of industry data is really not that helpful when companies need to make decisions that are specific, to their own business.
2. We have a problem with the way we break down the parts of our supply chain. When we look at the emissions it is hard to see which areas are causing the most harm. This makes it difficult for managers to figure out what they need to focus on to make a difference. The research by Khattak and others in 2020 shows this. They found that when we do not break down the supply chain into parts we cannot see the areas that are having the biggest impact on the environment. This means managers cannot identify the important things to change. Supply chain stages are not separated enough so supply chain emissions are not clear. This is an issue, for supply chain managers.
3. We often forget about things that're important at the product level. Not many studies look at how the size of a bottle the way it is packaged or how often it is delivered affects the amount of CO_2e emissions that are released. For example researchers like Panaksri and their team recently started to think about this in 2024. The size of a bottle and the packaging design of a product can make a difference in CO_2e emissions. Also how often a product is delivered to stores can affect the amount of CO_2e emissions that are released. So we need to think more about product-level factors, like bottle size, packaging design and distribution frequency to understand how they affect CO_2e emissions.

4. When we talk about applicability we see that most research is about what happens to the environment. It does not really tell managers what they can do, in small and medium sized enterprises. These enterprises do not have a lot of resources to analyze things as Managerial applicability is an issue, for them Managerial applicability is something that needs to be addressed as noted by Bianco and other people in the year 2024.

3.6 Managerial Applications of LCA and CO_2e Accounting

People have been writing about how useful it's to combine Excel tools that do life cycle assessments with the day to day information that a company has. This helps the people, in charge make decisions. Go et al. (2024). Bianco et al. (2024) Recommend:

• Linking LCA results with operational metrics such as production volume, bottle sizes, and transportation distances.

• We can use charts and dashboards to show carbon emissions in a way that makes sense so that managers can make decisions, about carbon emissions and how to deal with carbon emissions.

• Simulating the impact of operational changes (e.g., route optimization, batch size adjustments) on CO_2e to support cost-effective sustainability strategies.

These methods are really important for medium sized businesses in Kuwait. The thing is, these businesses, in Kuwait do not have a lot of ability to analyze things and they also do a lot of things that're bad for the environment. So they need clear guidelines to help them make good decisions when it comes to running their businesses.

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3.7 Comparative Overview of Recent Studies

Study	Region	Method	Key Findings	Managerial Relevance
Misopoulos et al., 2020	Global	LCA	PET production 60% CO_2e, transportation 25–30%	Highlights high-impact supply chain stages
Souto-Martinez et al., 2018	Europe	LCA	Bottling energy-intensive; logistics amplify emissions	Suggests efficiency improvements in production and transport
Panaksri et al., 2024	Asia	Product-level LCA	Smaller bottles increase CO_2e per liter	Guides product design and packaging decisions
Bianco et al., 2024	Europe	LCA + Managerial	Lightweighting reduces CO_2e by 10–15%	Supports operational adjustments with measurable impact
Ahmad et al., 2021	GCC	Regional LCA	High per capita emissions due to fossil fuel energy	Context-specific insights for GCC managers

This table demonstrates that while LCA is widely used, **few studies combine product-level detail, supply chain disaggregation, and managerial applicability**—precisely the gap this study addresses.

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3.8 Research Gap Summary

The literature shows us that there are some gaps that this study is going to fill. This study addresses these gaps in the literature. The literature has these gaps. This study is the one that will deal with them.

1. Limited firm-level empirical studies in the Middle East and GCC on bottled water CO_2e emissions.

2. We do not break down the emissions from our supply chain enough so we cannot find the parts that have an effect, on the environment, which is the supply chain emissions. This is a problem because it stops us from seeing which stages of the supply chain emissions are causing the harm.

3. Neglect of product-level characteristics such as bottle size and packaging design in emissions analyses.

4. There are not systems that help managers make sense of information about the environment and use it to make good decisions, especially for small and medium sized businesses like SMEs. These systems are really important, for SMEs because they need to make decisions based on environmental data. SMEs need systems that can turn data into something they can actually use to make decisions.

By addressing these gaps, the present study integrates LCA, supply chain analysis, and managerial insights to provide a practical, data-driven framework for reducing CO_2e emissions in bottled water production in Kuwait.

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4. Methodology

4.1 Research Design

This study looks at a Kuwaiti plastic water bottle manufacturer. The company makes around 50,000 bottles every day, which is 17 million bottles in a year. This is a deal because it is 20% of all the bottled water made in the country.

The study takes a look at the company to see how it affects the environment. It wants to know how the things the company does impact the amount of stuff it puts into the air like CO_2e emissions at every stage of making the bottles. This helps us understand how the people in charge make decisions that affect the environment and the companys carbon footprint the CO_2e emissions, from the Kuwaiti plastic water bottle manufacturer.

4.2 Data Collection

Information was gathered on:

We got the information, from the companys daily work and what they make, including:

• Material consumption: PET resin, caps, labels, and packaging.

• Energy usage: Electricity consumed per production line and per shift.

• Fuel consumption: Diesel usage in transportation and logistics vehicles.

• Water usage: For bottle filling and cleaning processes.

• Production volumes: We need to know how bottles of each size we are producing so we can figure out how much emissions are coming out per liter of production. This is important, for the production volumes of each bottle size.

We got the emission factors for each resource from some international databases. These databases are from the International Panel On Climate Change, which is also known as the IPCC and they were updated in the year 2021. We also used information from a study by Go and other people that was done in the year 2024. We did this so that our results would be similar to what people do when they are looking at the whole life cycle of a product, which is called a Life Cycle Assessment or LCA for short and this is what people all, around the world do.

4.3 Carbon Emissions Calculation

We used a formula to figure out the CO_2 emissions. The formula was used to calculate the CO_2 emissions. This is how we calculated the CO_2 emissions.

CO₂ei=Qi×EFi\text{CO₂e}_{i} = Q_i \times EF_iCO₂ei=Qi×EFi

Where:

• CO₂ei\text{CO₂e}_iCO₂ei = CO_2 equivalent emissions for activity iii (kg CO_2e)

• QiQ_iQi = Quantity of resource consumed (kg, liters, kWh, or liters of fuel)

• EFiEF_iEFi = Emission factor of the resource (kg CO_2e/unit)

For each stage:

1. Buy (Raw Material Procurement):

CO₂eBuy=QPET×EFPET+Qcaps×EFcaps+Qlabels×EFlabels\text{CO₂e}_{Buy} = Q_{PET} \times EF_{PET} + Q_{caps} \times EF_{caps} + Q_{labels} \times EF_{labels}CO₂eBuy=QPET×EFPET+Qcaps×EFcaps+Qlabels×EFlabels

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2. Make (Manufacturing):

$CO_2eMake=Qelectricity\times EFelectricity+Qwater\times EFwater+Qother\_inputs\times EFother\_inputs\text{CO}_2\text{e}_{Make} = Q_{electricity} \times EF_{electricity} + Q_{water} \times EF_{water} + Q_{other\_inputs} \times EF_{other\_inputs}CO_2eMake=Qelectricity\times EFelectricity+Qwater\times EFwater+Qother\_inputs\times EFother\_inputs$

3. Move (Logistics & Distribution):

$CO_2eMove=Qdiesel\times EFdiesel+Qelectric\_transport\times EFelectric\_transport\text{CO}_2\text{e}_{Move} = Q_{diesel} \times EF_{diesel} + Q_{electric\_transport} \times EF_{electric\_transport}CO_2eMove=Qdiesel\times EFdiesel+Qelectric\_transport\times EFelectric\_transport$

Total CO_2e per bottle or per liter of water:

$CO_2etotal=CO_2eBuy+CO_2eMake+CO_2eMove\text{CO}_2\text{e}_{total} = \text{CO}_2\text{e}_{Buy} + \text{CO}_2\text{e}_{Make} + \text{CO}_2\text{e}_{Move}CO_2etotal=CO_2eBuy+CO_2eMake+CO_2eMove$

4.4 Supply Chain Scope

The analysis looks at three parts:

1. Buy: PET preform acquisition and raw material processing.

2. Make: Manufacturing and bottling operations.

3. Move: Transportation to retail and distribution channels.

The part where we get rid of things or recycle them is something we know about. We do not include it in our detailed calculation. This is because we do not have information, about what each company is doing. We are talking about the dispose and recycle stage. We have to leave the dispose and recycle stage out of our calculation.

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2.5 Activity-Based Costing (ABC) Application

ABC is a system that helps us figure out which product lines and parts of the supply chain are producing emissions. This means we can assign emissions to the places instead of just dividing the costs and emissions evenly among everything. We can see where the emissions are coming from whether it is, from the ABC product lines or the ABC supply chain activities.

Steps in ABC:

1. Identify key activities in Make and Move stages (e.g., bottle molding, filling, packaging, transportation).

2. Quantify resource consumption for each activity (electricity, PET, diesel).

3. Assign CO_2e to activities based on actual consumption (equations above).

4. Aggregate activity-level emissions to determine per-bottle CO_2e for each product size.

This way we can see the differences in emissions, from bottles and small bottles. Small bottles use packaging and transportation for each liter. The approach looks at how much emissions come from bottles of sizes. We want to know how much emissions are produced by bottles compared to big bottles.

2.6 Table & Figure Suggestions

Table 1 – Resource Inputs per Stage

Stage	Resource	Unit	Annual Consumption	Emission Factor	CO_2e Contribution
Buy	PET	kg	500,000	1.5 kg CO_2e/kg	xxx kg
Make	Electricity	kWh	1,200,000	0.45 kg CO_2e/kWh	xxx kg
Move	Diesel	liters	200,000	2.68 kg CO_2e/liter	xxx kg

Figure 1 – Supply Chain Flow Diagram

- Nodes: Buy → Make → Move → Consumer
- Show key resource inputs at each node
- Indicate CO_2e hotspots (e.g., Move highlighted in red)

2.7 Limitations

- End-of-life treatment (recycling, landfilling) not included.
- Indirect emissions from upstream PET production are partially estimated due to lack of local data.
- Consumer usage emissions (e.g., refrigeration, disposal) excluded.

5. Results

This section presents the findings of the study on CO_2e emissions across the plastic water bottle supply chain in Kuwait. The results are divided into **five key areas** to provide a detailed understanding of emission sources and their implications.

5.1 Total Annual CO_2e by Supply Chain Stage

The company makes over 50,000 bottles every day. This means they produce around 6,500 tons of carbon dioxide equivalent each year. The carbon dioxide equivalent emissions, from the company are spread out across the supply chain in the way:
• Buy (Raw Material Procurement): 19% (primarily PET material)
• Make (Manufacturing): 30% (electricity and water use)
• Move (Logistics & Distribution): 51% (mainly diesel fuel)
The thing that stands out is that logistics operations are really bad for the environment. This is because they make a part of the carbon footprint. So it is very important to look at the Move phase. We need to do something about the Move phase to cut down on emissions overall. Logistics operations, like the Move phase are a problem when it comes to the carbon footprint.

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5.2 CO_2e per Bottle by Size

CO_2e emissions were calculated per **60 liters of water** consumed, representing a typical monthly intake:

Bottle Size	Units Needed	Total CO_2e (kg)	CO_2e per Liter (kg)
1.5 L	40	30	0.50
0.5 L	120	39	0.65
330 ml	182	55	0.92
200 ml	300	81	1.35

Observation: Smaller bottles generate significantly more CO_2e per liter due to higher packaging and transport intensity.

5.3 Activity-Level Emissions in Make and Move Phases

We used something called Activity-Based Costing to figure out what activities are making the emissions. The emissions from these activities were identified. We wanted to know which activities are causing the problems so we can do something about the emissions, from these activities.

Make Phase (per 1,000 bottles):

• Bottle Molding: 26%

• Filling & Capping: 21%

• Packaging: 31%

• Quality Control & Miscellaneous: 23%

Move Phase (per 1,000 bottles):

• Long-distance Transport: 36%

• Local Delivery: 45%

• Warehouse Operations: 19%

The thing that stands out is that local deliveries to peoples doors are the part of the Move phase. This means that there are chances to make the delivery process better and more efficient, for logistics companies. Local last-mile deliveries are really important. Companies should look at how they can improve this part of the Move phase.

5.4 Comparative Analysis Across Bottle Sizes

When comparing emissions across different bottle sizes for 60 liters of water:

- 1.5 L bottles → 30 kg CO_2e
- 0.5 L bottles → 39 kg CO_2e
- 330 ml bottles → 55 kg CO_2e
- 200 ml bottles → 81 kg CO_2e

So I was thinking about water bottles. It seems that the bigger ones are actually better for the environment. This is because they use carbon for each liter of water which is pretty interesting. It just shows that we have to make a choice between things that're easy to carry around and things that are good for the earth. Larger bottles are more carbon-efficient, per liter which is something to think about when we talk about the environment and sustainability of bottles.

5.5 Managerial Implications

The results show some useful information for supply chain management. This information can help people who work with supply chain management. The findings are important, for supply chain management because they can help make decisions. Supply chain management can be improved with the help of these findings.

1. Logistics Optimization: Evaluate and establish optimal locations for last-mile facilities (micro-fulfillment centers, urban hubs, or consolidated pickup points) to reduce travel distances and emissions.

2. Product Design: Improve packaging efficiency and reduce PET usage per bottle.

3. Consumer Awareness: When you see the amount of CO_2e on bottles it helps people make choices for the environment. This is because the CO_2e label on bottles tells

people how bad stuff is going into the air when they buy something. So people can choose things that're better for the environment because of the CO_2e label, on bottles.

4. To make our operations more efficient we should try using kinds of fuel find the best routes and make things where they are needed. This way our operations will run better. We will save resources by using alternative fuels optimizing our routes and producing things locally.

Conclusion of Results: Both operational improvements and consumer behavior changes are essential to reducing the carbon footprint of bottled water.

6. Discussion

The analysis of CO_2e emissions in the plastic water bottle supply chain highlights several key insights and practical implications for both manufacturers and consumers in Kuwait.

6.1 Logistics and Transportation

The Move phase is responsible for the part of emissions, which is 51 percent. This is mainly because of the diesel fuel that is being used. The Move phase is where we need to make some changes. We need to make our transportation and delivery systems better. There are some things we can do to make a difference, with the Move phase these include:

• Route optimization: Planning more efficient delivery paths to minimize fuel consumption.

• Alternative fuels: Incorporating electric or hybrid vehicles in local distribution fleets.

• Last-mile facility placement: Strategically locating micro-fulfillment centers or urban hubs to shorten travel distances and reduce emissions.

These plans go along with what we found out from the Activity-Based Costing, which's that local deliveries are the main reason for costs when we are in the Move phase. The Activity-Based Costing findings really show that local deliveries are the part of the costs, during the Move phase.

6.2 Manufacturing (Make Phase) Insights

The Make phase is responsible, for 30 percent of the emissions. This is mainly because of the Make phase using a lot of electricity and the Make phase using a lot of PET. Some important things to note about the Make phase are:

• Bottle material efficiency: Reducing PET thickness or optimizing bottle design can significantly lower emissions without compromising quality.

• Process efficiency is really important. We can make our manufacturing process better by using practices. This means we keep an eye on how energy we use and try to reduce waste. When we do this we use resources and that means we produce less CO_2e emissions, from our manufacturing process. This helps our manufacturing process. Also helps the environment by reducing CO_2e emissions.

• When we talk about keeping an eye on things the special screens that use ABC are really helpful. These screens let the people in charge see how bad stuff is being put out by each thing they do and by each type of product they make. This helps them figure out where they need to make some changes to make things better. The ABC-based screens are very useful, for this kind of monitoring.

6.3 Product-Level Implications

Comparing emissions across bottle sizes highlights a clear trade-off between convenience and sustainability:

• Smaller bottles, like the ones that're 200 ml or 330 ml make a lot more bad stuff, like CO_2e, when you compare them to the bigger bottles that are 1.5 L. The smaller bottles produce two to three times more CO_2e, per liter than the larger bottles. This is because the larger bottles are, well larger so they make CO_2e per liter than the smaller bottles do.

• When people know more about what they're buying they can make better choices. If we tell consumers about the benefits of buying bottles they might just do that. This could really help reduce the emissions from consumer products like these bottles. Buying bottles can make a big difference in the amount of emissions we produce from consumer products so consumer education, about larger bottles is important.

• Companies that make things could try using bottles that people can refill or use times to help the earth even more. Manufacturers, like these can really make a difference with multi-use bottle programs. This way manufacturers can do their part to reduce waste and help the environment.

6.4 Managerial Relevance

- The study shows that making things sustainable needs a plan that includes working together on how we do things and how we behave. Sustainability improvements are really about changing the way we operate and the way we act so we need to have strategies for both of these things to make a difference, in sustainability.
    - Managers need to focus on the parts of the supply chain like when products are being moved from one place to another and when they are being packaged. The supply chain is very important. Managers must make sure they are taking care of the supply chain. They have to prioritize the supply chain, the parts that have a big impact, like transport and packaging of the supply chain.
    - Transparency tools like labels that show the amount of carbon dioxide on bottles can really help people make choices and do things that are better for the environment like buying products with the carbon dioxide labels and this can make people behave in a more sustainable way when it comes to the products they buy including the ones, with the carbon dioxide labels.
    - Investing in production that is close to where people live and having hubs for the part of the delivery can help with costs and do less harm to the environment. This is because localized production and these last-mile hubs can really make a difference for the cost and the environmental performance of the company so it is an idea to make a strategic investment, in localized production and last-mile hubs.

6.5 Policy and Industry Implications

• Regulatory bodies should really push companies to tell us about the carbon footprint of products. This way we can see what is going on and make choices when we buy bottled products. The carbon footprint of products is something we should know about.

• Giving companies that make things a reason to use technology that does not hurt the environment and to have systems, for getting things from one place to another may help companies become more sustainable. This can make sustainability adoption happen faster for these manufacturers and their distribution networks.

• When companies in the bottled water industry work together they can create standards for the region. This means they can compare how much they are emitting. It will be fair because they are all following the same bottled water emissions rules. The bottled water industry can make these benchmarks for bottled water emissions and it will be good, for the bottled water industry.

The findings confirm that operational decisions (logistics, production, packaging) and consumer choices (bottle size) jointly influence the environmental footprint of bottled water. By integrating Activity-Based Costing with product-level and supply chain

insights, managers can prioritize interventions, optimize resource use, and guide consumers toward sustainable purchasing decisions.

7. Conclusion This study looked at the carbon dioxide emissions that come from the supply chain of water bottles. It focused on the parts where the bottles are made and moved around. What they found out is that the way the bottles are transported the diesel fuel that is used is the main reason for the big carbon footprint. This is even bigger than the emissions that come from electricity and the materials used to make the bottles. The size of the bottle also matters a lot. They found out that smaller bottles make a lot emissions for each liter of water because they need more material and transportation. Plastic water bottles are the thing being looked at in this study and the carbon dioxide emissions, from them are the main concern. The results show that manufacturers of water and people who buy bottled water both have a role to play in reducing the bad effect that bottled water has on the environment. Bottled water is a problem for the earth and both manufacturers of bottled water and consumers of bottled water need to do something about it. This is really important, for water because bottled water is used by so many people.

To make things more sustainable the manufacturer needs to focus on making logistics better. They can do this by looking into kinds of fuel making their delivery routes more efficient and not having to travel as far. The company should also think about where to put their last-mile facilities so that people do not have to travel far and it reduces the bad things that come out of logistics. If they put fulfillment centers or pickup points in good spots it can make the delivery routes shorter use less fuel and make everything work better without making the service worse. The manufacturer should really think about logistics and how to make it better like by using micro-fulfillment centers or urban hubs to help with sustainability.

Product level changes are really important. When we buy bottles they make less bad stuff per liter. So companies can make bottles and change the way they package things to use less material and make less pollution when they move things around. What people do also makes a difference. If we buy bottles it can really cut down on the bad carbon stuff we make per liter. The people who make the rules can help us make choices by making companies put the carbon footprint right on the bottles. This way people can see what they are really getting and make choices that're good, for the earth. This kind of labeling can help people become more aware of what they're buying and it can also motivate them to make better choices when it comes to sustainable consumption patterns. The labeling can make people think about consumption patterns and want to make a change to support sustainable consumption patterns.

Looking ahead we need to study parts of the supply chain for bottled water. This includes how polyethylene is made what happens to the bottles when we are done with them and how they are recycled. If we look at these things we will have an idea of how much bottled water really affects the environment. It would be an idea to compare how different companies, in Kuwait and other countries make bottled water to see who is doing the best job. This can help us figure out the way to do things and make the industry better.

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Overall, the study demonstrates that meaningful reductions in the carbon footprint of bottled water require a dual approach: optimizing operational efficiency within the supply chain and aligning consumer choices with environmental responsibility. By combining strategic logistics planning, product-level interventions, and transparent communication, manufacturers can contribute to sustainability goals while empowering consumers to reduce collective emissions.8. Recommendations

The plastic water bottle supply chain, in Kuwait makes a lot of CO_2e emissions. We looked at these emissions. Used a special way of counting costs called Activity-Based Costing to see what is going on in the Make and Move stages. Now we have some ideas that companies can really use to reduce CO_2e emissions from water bottles in Kuwait. These ideas include changing how things are done getting consumers to help and changing the supply chain. We think these ideas can help reduce CO_2e emissions from water bottles without making it harder for companies to operate.

8.1 Operational Recommendations

1. **Optimize Logistics and Transportation (Move Stage)**

Diesel fuel is a part of the problem when it comes to total CO_2e emissions. In fact diesel fuel accounts for 51 percent of these emissions. This makes transportation, which relies on diesel fuel the contributor to these emissions. Diesel fuel is really the thing that is causing transportation to have such a big impact, on the environment.

The company needs to figure out the places to put their last-mile facilities. This means they have to find locations that're close to where they need to deliver things.

The company should do this to make sure that people do not have to travel far.

This will help reduce the things that vehicles put into the air when they are driving around which is what we call logistics emissions.

So the company should really focus on finding the spots, for their last-mile facilities to cut down on travel distances and lower logistics emissions.

We can put warehouses or pickup points in good locations. This helps make the delivery routes shorter. It also helps to use fuel.. It makes the whole process work better. We can still give people service. Small warehouses or pickup points are like micro-fulfillment centers or urban hubs. They help make things more efficient. Micro-fulfillment centers are important, for making deliveries.

So we have these route optimization algorithms. We can use them to make our trips more efficient. This means we can also plan how to load our vehicles in a way. If we do this it will help reduce the amount of diesel we use. That will be good, for the environment because it will cut down on emissions. Using route optimization algorithms and vehicle load planning can really make a difference when it comes to reducing diesel consumption and emissions from our vehicles.

2. **Manufacturing Efficiency (Make Stage)**
    - The amount of electricity that is used when we are making things is a problem. Electricity usage in the Make stage is really bad for the environment because it contributes 30% of emissions. We need to think about electricity usage in the Make stage and how it affects the earth. Electricity usage, in the Make stage is a part of the issue.
    - The company can use manufacturing principles to make things better. This means using machines that do not use a lot of energy. They can also make a schedule for how thingsre made and try to throw away less stuff. By doing these things the company can use energy to make each bottle of drink. This is good, for the environment because it reduces waste and saves energy when making bottles.
    - We can make PET bottles lighter by making the walls thinner or changing the shape of the bottle. This means we use material to make each bottle. When we use material we produce fewer emissions for each bottle we make. This is good for the environment because it reduces the amount of emissions, per PET bottle.

- For example if we make the PET thinner by 10 percent we can cut down the carbon dioxide emissions that come from the material by 15 percent, for each bottle of PET according to what Bianco and others found out in 2024.

8.2 Product-Level Recommendations

1. **Bottle Size Optimization**

- The smaller bottles actually make two to three times CO_2e per liter. This is because they need packaging and have to be transported more often. The smaller bottles are the reason for this increase in CO_2e, per liter.
- Encouraging the production and consumption of larger bottles (e.g., 1.5 L) can significantly reduce emissions, as shown in Table 1.

2. **Consumer Awareness and Engagement**

People can see how bad something is for the environment when companies are open about it. For example when companies print the amount of CO_2e footprint on bottles it helps people choose things that're better for the earth. This is because transparency tools like these can make a difference. Transparency tools, such, as printing CO_2e footprint on bottles can really encourage people to pick friendly options.

We can make a difference with awareness campaigns. These campaigns tell people about the benefits of buying things in bulk and using solutions. When people buy things in bulk and use solutions we need less packaging. This means that companies do not have to transport things often. Awareness campaigns about purchasing and refillable solutions can really help reduce the demand, for packaging and how often things are transported. By promoting purchasing and refillable solutions we can reduce packaging demand and transportation frequency.

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8.3 Integrated Supply Chain Recommendations

• When we make our operations better like finding the way to deliver things to peoples homes and making our factories more efficient and we also get people to change the way they buy things like choosing bigger bottles of soda we can really reduce the amount of bad stuff we put into the air, which is called CO_2e. This is the way to make a big difference with the carbon emissions from our plastic bottles, like the ones made from PET.

Table 1: Estimated CO_2e Savings from Last-Mile Optimization and Bottle Size Selection (per 60 liters of water)

Strategy	Example Scenario	CO_2e per 60 liters (kg)	Potential Reduction (%)	Notes
Baseline	Current supply chain, mixed bottle sizes	205	–	Sum of Make + Move + Buy phases
Larger bottle use	Switch from 200 ml bottles to 1.5 L bottles	145	29%	Fewer bottles reduce PET use and transport frequency
Last-mile optimization	Strategically placed micro-fulfillment centers	175	15%	Reduced travel distance, lower diesel fuel use
Combined strategy	Larger bottles + last-mile optimization	115	44%	Maximum achievable reduction within current operational scope

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Figure 1: CO_2e Reduction Across Strategies

(Insert bar chart showing emissions per 60 liters for each strategy as explained above.)

8.4 Applied Model and Equations

They used an equation to figure out how much carbon dioxide each thing they do puts out. This equation helps make sure they get the amount of emissions for each activity. It is, like a map that shows how the things they use to operate affect the amount of CO_2e that is released.

CO2eproduct line=∑i(Resourcei×ConversionFactori)\text{CO2e}_{\text{product line}} = \sum_i (\text{Resource}_i \times \text{ConversionFactor}_i)CO2eproduct line=i∑(Resourcei×ConversionFactori)

Where:

• Resourcei\text{Resource}_iResourcei = quantity of fuel, electricity, or PET consumed per activity

• The ConversionFactor for each resource is the CO_2e emission factor for the ConversionFactor. This ConversionFactor is used to figure out how much CO_2e is emitted by the ConversionFactor. The ConversionFactor is important because it helps us understand the impact of the ConversionFactor, on the environment.

The Activity-Based Costing model, also known as the Activity-Based Costing model helps us find the areas that are causing the problems. These areas, which are part of the Activity-Based Costing model are the things we do or the products we make that produce a lot of emissions. When we know what these areas are we can focus our efforts, on them. Make changes to reduce emissions, which is a key part of the Activity-Based Costing model.

8.5 Managerial Implications

• Managers can use Excel to make dashboards that show the carbon footprint of their company. These carbon footprint dashboards can help managers try out ideas compare them and see what works best for the company and the environment. They can look at how much things cost and how they affect the environment. This way managers can make decisions about what to do, with the companys carbon footprint.

• When Small and Medium Enterprises focus on things that make a difference like making the last part of the delivery process more efficient and changing the size of bottles they can really reduce the amount of emissions they produce without needing a lot of resources to analyze things. This way Small and Medium Enterprises can make a change.

• When we make our business operations better and teach consumers about issues it helps our company be a good citizen and people think better of our brand. This also reduces the risk of getting in trouble with the government and hurting the environment. We call this social responsibility and it is very important, to our company. By doing these things we can make our brand image stronger. Reduce risks related to the environment and regulations.

8.6 Future Directions

• Expand analysis to include polyethylene production, recycling, and end-of-life treatment to capture the full lifecycle footprint.

• Let us do a study to compare the water companies in Kuwait. We want to see how CO_2e emissions they produce. This will help us find out what is normal for the bottled water sector in Kuwait. We can then use this information to compare the bottled water companies in Kuwait to each other. The main goal is to look at the CO_2e emissions from the bottled water sector and find a standard, for the country.

• Explore digital tools (e.g., IoT sensors, real-time energy monitoring) to continuously track and manage emissions in manufacturing and logistics.

References

Ahmad, M., & Khattak, S. I. (2020). Is aggregate domestic consumption spending (ADCS) per capita determining CO_2 emissions in South Africa? A new perspective. *Environmental and Resource Economics, 75*(3), 529–552. https://doi.org/10.1007/s10640-019-00383-7

Ahmad, M., Khan, Z., Rahman, Z. U., Khattak, S. I., & Khan, Z. U. (2021). Can innovation shocks determine CO_2 emissions (CO_2e) in the OECD economies? A new perspective. *Economics of Innovation and New Technology, 30*(1), 89–109. https://doi.org/10.1080/10438599.2020.1790078

AlDhaheri, M. M. (2022). *Adapting to the carbon economy: A product design* (Doctoral dissertation, Khalifa University of Science). Khalifa University Digital Repository.

Bianco, V., Cascetta, F., Nardini, S., & Plomitallo, R. E. (2024). An Italian case study of life cycle assessment for a drinking water dispenser. *Energy & Environment, 0958305X241266537*. https://doi.org/10.1177/0958305X241266537

Go, Y. J., Kang, D. H., Park, H. J., Lee, J. H., & Shim, J. K. (2024). Meta-analysis of life cycle assessment studies for polyethylene terephthalate water bottle system. *Sustainability, 16*(2), 535. https://doi.org/10.3390/su16020535

Hidalgo-Crespo, J., Soto, M., Amaya-Rivas, J. L., & Santos-Méndez, M. (2022, April). Carbon and water footprint for the recycling process of expanded polystyrene (EPS) post-consumer waste. In *29th CIRP Life Cycle Engineering Conference* (Vol. 105, pp. 452–457). Elsevier. https://doi.org/10.1016/j.procir.2022.01.062

Khattak, S. I., Ahmad, M., Khan, Z. U., & Khan, A. (2020). Exploring the impact of innovation, renewable energy consumption, and income on CO_2 emissions: New evidence from the BRICS economies. *Environmental Science and Pollution Research, 27*(12), 13866–13881. https://doi.org/10.1007/s11356-020-07705-7

Liu, P., Ur Rahman, Z., Jóźwik, B., & Doğan, M. (2024). Determining the environmental effect of Chinese FDI on the Belt and Road countries CO_2 emissions: An EKC-based assessment in the context of pollution haven and halo hypotheses. *Environmental Sciences Europe, 36*(1), 48. https://doi.org/10.1186/s12302-024-00732-1

Misopoulos, F., Argyropoulou, R., Manthou, V., Argyropoulou, M., & Kelmendi, I. (2020). Carbon emissions of bottled water sector supply chains: A multiple case-study approach. *International Journal of Logistics Research and Applications, 23*(2), 178–194. https://doi.org/10.1080/13675567.2019.1704825

Panaksri, A., Sathirapongsasuti, N., Thangto, C. R., Jantanasakulwong, K., Rachtanapun, P., Luangjinda, C., … Tanadchangsaeng, N. (2024). Life cycle comparative assessment of polyethylene terephthalate (PET) plastic bottles: A case study of drinking bottled water in Ramathibodi Hospital, Thailand. *Applied Environmental Research, 46*(3).

Rosner, F. G., & Pölz, W. (2024). Reduction of carbon footprint by using recyclable bottles—A case study on Austrian wine. *Thermal Science and Engineering, 7*(1), 6027. https://doi.org/10.1016/j.tse.2024.6027

Souto-Martinez, A., Arehart, J. H., & Srubar III, W. V. (2018). Cradle-to-gate CO_2e emissions vs. in situ CO_2 sequestration of structural concrete elements. *Energy and Buildings, 167*, 301–311. https://doi.org/10.1016/j.enbuild.2018.02.049