



# Item based CO<sub>2</sub>e emission calculation method

Silvia Leinonen

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## ABSTRACT

Tampereen ammattikorkeakoulu  
Tampere University of Applied Sciences  
Environmental Engineering

SILVIA LEINONEN

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Global warming is one of the main threats to the Earth, caused by the release of greenhouse gases. Gases are measured by their global warming potential (GWP), which is an air pollutant's relative potency to contribute towards global warming compared to CO<sub>2</sub> during a 100-year time period in the atmosphere. The related unit is CO<sub>2</sub>e (CO<sub>2</sub>-equivalent), and it commonly accounts for seven greenhouse gases, measured in kgCO<sub>2</sub>e/kg. GWP and the related CO<sub>2</sub>e are common climate metrics used in management and policies.

Teknikum Oy is a provider of polymer technologies, selling rubber and plastic components and products, used for example in agricultural, mining and railway industries. Teknikum Oy has opted into Science Based Targets initiative (SBTi), as such they have undertaken a full companywide CO<sub>2</sub>e assessment in 2020 following the Greenhouse Gas (GHG) Protocol. Since the GHG Protocol does not provide product specific CO<sub>2</sub>e factors, which are needed for process optimization and requested by clients, another tool is needed.

Teknikum Oy's item based CO<sub>2</sub>e tool accounts for the cradle-to-gate emissions and is utilizing the data collected for the GHG Protocol calculation. CO<sub>2</sub>e is calculated on a case-by-case basis for each item and customer. The tool was tested with a case calculation for a rubber component.

With the growing interest in environmental effects, reaching reduction targets, along with pressure from the public and governments, the demand for CO<sub>2</sub>e accounting is increasing. CO<sub>2</sub>e assessments provide additional marketing benefits, help in emission reduction, and provide basis for the analysis. A smaller CO<sub>2</sub>e value indicates more effective processes.

This thesis acts as the theory and validation of a such tool, and manual for the transparency and use of the tool. A tool such as this is tailored by the consultant to meet the needs of the client based on their unique company processes. Whilst a tool can provide a relatively reliable calculation, limited datasets can hinder accuracy and how the result is validated needs to be reported. The accounting results can both guide and imply, but a thorough environmental analysis requires multiple impact categories, and some of them could be qualitative. Overall, shifting from the dependency of the use of fossil fuels is key.

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Key words: global warming, greenhouse gas, carbon footprint

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**GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)**

GWP	Global warming potential
CO <sub>2</sub> e	Carbon dioxide equivalent emissions, unit kg CO <sub>2</sub> e/kg
GHG	Greenhouse gas
LCA	Life cycle assessment/analysis
SBTi	Science Based Targets initiative
EPD	Environmental Product Declaration
IPCC	The Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
CFC	Chloro-fluoro-carbons, chemical compounds
FSC	Forest Stewardship Council certificate

## 1 INTRODUCTION

Since the industrial revolution around the 1850s, industrial activity has utilized fossil fuels to power through combustion, releasing gases to the atmosphere in large scale. Along with allowing major growth, development, and wellness of people, emissions to air begun to slowly have harmful effects. The fuels are used more and more each year and the emissions have grown notably since the 1900s. According to statistics by the United States Environmental Protection Agency (EPA), compared to the levels of early 1970s, the emissions have increased by 90% and have not yet reached their peak (EPA 2023). The Intergovernmental Panel on Climate Change (IPCC) states in their climate change report in 2022, that “since the pre-industrial period, the land surface air temperature has risen nearly twice as much as the global average temperature” (IPCC 2022).

This is the situation even though already 80 years ago scientists have been warning us of the effects of greenhouse gas emissions in the atmosphere, and the contribution to global warming (NASA 2023).

Apart from the long-term environmental problems, air pollution has been a major health issue especially in places with large populations and industrial areas, as many people are affected. Some examples of catastrophic effects caused by air emissions include the Great Smog of London 1952, which caused the whole city to come to a halt and estimated 12 000 residents dead due to air pollution from coal burning (Martinez 2023), and the ozone layer depletion above Australia, caused by the heavy utilization of ozone-depleting chemicals, such as chloro-fluoro-carbons (CFCs) since the 1970s, causing Australia to have the most high numbers of skin cancer diagnoses in the world (O’Reilly n.d.).

Atmospheric concentrations of greenhouse gases are in continuous rise even though targets have been set for reduction. It is alarming that the emissions only continue to increase globally, and radical steps need to be taken to both reduce emissions and mitigate for some inevitable changes, which are expected to occur at the current rate of greenhouse gas release (NASA 2023).

IPCC's report on climate change, released early 2023, states that "pace and scale of climate action are insufficient to tackle climate change", so reaching these targets is vital (IPCC 2023). To achieve these steps to radically slow global warming and to mitigate in the changes in the ecosystems and biosphere, emissions need to be cut by all parties. To do this, emissions need to be calculated, it can be indicated where the changes can and should be made for the best impacts of reduction. In 2016, a legally binding international treaty on climate change by the United Nations, The Paris Agreement, was signed by 196 countries. In the Agreement, the importance of not crossing a threshold temperature rise of 1,5 Celcius over pre-industrial levels by the end of 21<sup>st</sup> century is being stressed. The crossing of 1,5 Celcius threshold is estimated to cause severe and more often occurring environmental disasters, such as extreme weather events from drought to flooding, mass destruction of biodiversity, mass immigration due to the increased area of uninhabitable land, and many other devastating effects (IPCC 2023).

Globally in 2016, energy use in industrial activity accounted for 24 % of greenhouse gases and an additional 5 % of industrial raw materials. About a third of global greenhouse gases came from industry in 2016 (Richie et al. 2020). Therefore, industries are in a large role in affecting the release of greenhouse gases which contribute towards global warming. The European Union 2030 Climate Target Plan includes cutting greenhouse gas emissions by at least 55% by 2030 compared to levels in 1990 and becoming carbon neutral in 2050 (European Commission n.d.). Industries around the world are participating in the process through various environmental initiatives, permits, policies and targets.

Teknikum Oy is a provider of polymer technology, selling rubber and plastic designs for various purposes. Their products are industrial hoses and couplings, technical foam products, rubber linings, and compounds and development. Their products are used for example in agricultural, mining and railway industries. Teknikum Oy is a Finnish company, with their head office located in Sastamala, Pirkanmaa Region. They've established their agenda as "a pioneer in sustainable development in polymer technology". (Teknikum 2022.)

At Teknikum Oy, their sustainability report from 2022 promises to align their climate targets with the Paris Agreement to reach net-zero by 2050 and to limit

global warming to 1.5 Celcius. To support this, they have obtained a voluntary pathway, Science Based Targets initiative (SBTi), to assess emissions and follow their development, as knowing one's emissions is vital to be able to make reductions in them (Teknikum 2022.) SBTi includes a greenhouse gas calculation following a Greenhouse Gas (GHG) Protocol standard with certain set categories, which are called Scopes.

To provide for their stakeholder's and customer's needs for environmental management and reporting and to understand the emissions behind each item, a CO<sub>2e</sub> emission coefficient per sold item kilogram should be known. For these purposes the calculation tool was built. The knowledge of emissions per item variables can be useful when marketing and developing, or researching products and processes, and can be valuable for customers and partners. In the future, these life-cycle practices will become more common and might become a requirement for certain activities, along with pressure from clients and stakeholders, as it will be beneficial for all to understand how a product affects the environment in certain categories.

Today, in the Finnish Environmental Protection Law, permitting can require certain monitoring and give guidelines on emission levels allowed by industries according to the Finnish National Air Quality Protection Programme, mentioned in the protection law 2014/527 149 c § (Finlex 2014). Teknikum Oy has applied and been granted an Environmental Permit for operations.

In this thesis, a tool for calculating item based global warming potential (GWP, unit CO<sub>2e</sub>) of Teknikum Oy's products is created. Teknikum Oy's processes are included in the tool in the scale from cradle to gate, which means the emissions from raw material to finished product. Use stage and end-of-life management are not included in the tool due to large variety of possibilities that can significantly affect the reliability of the tool. The tool provides a CO<sub>2e</sub> value for a client to include in their own emission calculations to the point of purchase.

## 2 GLOBAL WARMING POTENTIAL IN INDUSTRY

In industry, the greenhouse gas emissions are related to the use of fuels and other chemicals. The emission's potency to affect climate change is measured as global warming potential (GWP), which accounts for GHG's set by the UN's Kyoto Protocol.

Kyoto Protocol is operating in the United Nations Framework on Climate Change (UNFCCC) since 1997, specifying to industries management to limiting and reducing of greenhouse gas emissions. Kyoto Protocol wasn't brought into effect before 2005 due to an extensive contract approval process (UNFCCC n.d.). The Protocol addresses countries with industrialized activity, giving targets of emission limiting and reducing only binding to developed countries, since it recognizes how the emissions are distributed unequally between countries, with these countries being highly responsible for the majority of GHG's release. The Protocol itself is requiring these countries to commit to reducing policies, mitigation, and adaptation measures, and to report their development regularly. For Kyoto Protocol, reporting of annual national emission inventories, there are seven GHG reported in the form of carbon dioxide equivalence. (GHG Protocol 2023.)

From this, and with the help of IPCC's resources, The GHG Protocol has developed a CO<sub>2</sub> equivalence list to report emissions as a united GWP of CO<sub>2</sub> equivalent to assess required greenhouse gases in inventories. The UNFCCC/Kyoto Protocol emission inventory, and IPCC's requirements have been incorporated into the GHG Protocol emission inventory standards.

### 2.1 Carbon Dioxide Equivalent CO<sub>2</sub>e

Global warming potential (GWP) is the basis for assessing the potency of a greenhouse gas to contribute towards climate change. One of the most common units is CO<sub>2</sub>e or sometimes written as CO<sub>2</sub>-eq. CO<sub>2</sub>e is a measure in the metric system used to compare the emitted greenhouse gases on the basis of their GWP, by converting amounts of other greenhouse gas emissions to the equivalent amount of CO<sub>2</sub>, with the same global warming potential. (Eurostat n.d.)

A CO<sub>2</sub>e value of 1 means the equivalent of one kilogram of CO<sub>2</sub> greenhouse gas was emitted in the process, and it has the effect of one kilogram of CO<sub>2</sub> in the atmosphere, but the gases could have been any and the amount emitted could be significantly less. GWP is an air pollutant's relative potency to contribute towards global warming compared to CO<sub>2</sub> during a 100-year time period in the atmosphere. The related unit CO<sub>2</sub>e commonly accounts for seven greenhouse gases, measured in kgCO<sub>2</sub>e/kg. These gases, decided upon in Kyoto Protocol, can be found in table 1.

For example, methane has a GWP of 28 compared to 1 CO<sub>2</sub>, according to the IPCC and GHG Protocol - differences between some gases GWP are significant, as some compounds are more potent than others (table 1). The GWP is more inclusive when assessing emissions compared to the focus on carbon dioxide footprints, as it can be understood that the reported CO<sub>2</sub> values can be misleading, if other gases with larger GWP are neglected or reported individually, and their values can seem small to an interpreter who doesn't sufficiently know and understand the potency difference.

<b>Greenhouse gas</b>	<b>GWP (kg CO<sub>2</sub>e/kg)</b>
Carbon dioxide (CO <sub>2</sub> )	1
methane (CH <sub>4</sub> )	28
Nitrous oxide (N <sub>2</sub> O)	265
Hydrofluorocarbons (HFCs)	varies between 3 to 14 000
Perfluorocarbons (PFC's)	varies between 8 000 – 23 500
Sulfur hexafluoride (SF <sub>6</sub> )	23 500
Nitrogen trifluoride (NF <sub>3</sub> )	16 100

TABLE 1. Required accounted GHG's reported in GHG Protocol inventories (GHG Protocol 2013).

## 2.2 The GHG Protocol

With the growing interest in environmental effects along with pressure from the public and governments, the demand for CO<sub>2</sub>e calculations is increasing. CO<sub>2</sub>e

assessments provide additional marketing benefits, help in management of emission reduction, and provide basis for the analysis between processes. A smaller CO<sub>2e</sub> value indicates more effective processes and can increase profitability. Following these values allows for measuring and managing emissions.

Science Based Targets initiative (SBTi), steered by, for example, the UN, the World Resources Institute, and the World Wildlife Fund (WWF), is a voluntary pathway for corporations and organizations to manage and reach their GHG emission targets. Corporation emission reduction targets are considered “science-based” if they are aligned with the Paris Agreement of limiting global warming to 1,5 Celcius above pre-industrial levels and reaching net zero by the half of the millenium, hence the name of the initiative. The SBTi is ensuring that following the latest science, organizations are not in a position to make false or possibly greenwashing promises about their emissions with no way to follow, quantify or manage them. On their progress report in 2022, they’ve reached almost 1100 companies to set science-based targets and are seeing a 34 % reduction of emissions within the reporting companies between the years 2015-2020. (SBTi 2023.)

The GHG Protocol, A Corporate Accounting and Reporting Standard, is an assessment of GHG utilized by the SBTi, and reported in GWP, unit CO<sub>2</sub>- equivalent. The CO<sub>2e</sub> inventory is a simplified, one-category-fits-most approach to begin the workload in assessing a company’s or organisation’s environmental impact as greenhouse gas emissions (GHG Protocol 2023). The GHG Protocol addresses emissions from direct and indirect activity, and these are separated by three scopes. Scope 1 includes emissions from direct use of owned and controlled sources, such as use of fossil fuels as self-produced energy. Scope 2 emissions are indirect emissions from purchased energy and power, such as generation of electricity. Scope 3 includes everything indirect happening within the whole value chain, which are not already included in scope 2, such as raw materials, supply chains and transport of goods and staff. The scopes and their corresponding categories to the tool, with the share of total emissions of Teknikum Oy, are reported in table 2 in section 4.

GHG Protocol was created to fit the needs of companies and other parties interested in mapping and managing their emissions through, e.g., as used in this

thesis, Science Based Targets initiative. The Protocol allows for thorough standardized mapping of emissions and creates a common ground for comparison, management, and development for corporations, nations, and organizations.

As in any report of LCA or carbon footprint data collection, the selected appropriate inventory boundary adds relevance to the result. Here, it is important to include information of all relevant emission sources for completeness. To have meaningful data and follow up on progress, calculations should be done consistently, and apply all the necessary approaches. Reports shall be transparent, with specifically identified inclusions and exclusions, explaining the credibility.

### 3 TEKNIKUM OY

Teknikum Oy is a provider of polymer technology, selling rubber and plastic designs for various purposes. The company has been operational since the 1950s. Their products include industrial hoses and couplings, technical foam products, rubber linings, and rubber and plastic compounds and their development. Their products are used for example in agricultural, mining and railway industries. Teknikum Oy is a Finnish company, with their head office located in Sastamala, Pirkanmaa Region, where they are the largest employer. They've established their agenda as "a pioneer in sustainable development in polymer technology". (Teknikum 2022.)

Teknikum Oy's processes are with polymer compounds required by, just to mention, industrial activity. Their services and products include contract manufacturing for a tailored fitted rubber or plastic part of a specific need that require certain quality, eg. pressure, acidity, wear & tear, or temperature resistance. For this purpose, they develop materials to find the best fit for a needed consistency in their laboratories. (Teknikum Oy 2022.)

Products include industrial hoses for fluids (also food-graded), tyre components for cars and bicycles, plastic items for everyday use by households, and parts for mining, mills, and railway. These could be used for protection of surfaces and equipment, heavy-duty processes, vibration mats, and transfer of materials.

This tool was built by the request of the company and their marketing and EHSQ department. The company is interested in knowing which products or product lines have less carbon emissions, where the hotspots are, and what kind of changes can be made to reduce emissions. The overall assessment for the company wide CO<sub>2e</sub> emissions has been done in the year 2020 following the company's voluntary participation in the SBTi. It is an advantage to be able to provide product-specific information on the emissions to clientele.

### 3.1 Environmental Management and Sustainability

The environmental management of Teknikum Oy is practiced by the company's EHSQ (Environment, Health, Safety & Quality) department. The company has obtained quality, occupational health & safety and environmental ISO-standard certifications ISO 9001:2015, ISO 14001:2015 and ISO 45001 for their production sites in Finland. (Teknikum 2022.)

Teknikum Oy has published a Sustainability Report in 2023 explaining their quality, environmental, procurement and safety policies, on their website. Among them is Teknikum Oy's participation in the Science Based Targets initiative (SBTi), which allows the company to measure and manage their greenhouse gas emissions and reduce them according to Paris Agreement to mitigate climate change. As a part of the SBTi, the GHG's were accounted companywide. The accounting acts as a reference for the item-based emission tool. (Teknikum 2022.)

In September 2023, Teknikum Oy published news announcing their SBTi approved climate targets on their website: "Teknikum Group is committed to reducing its scopes 1 and 2 greenhouse gas emissions by 50% by 2030 compared with 2020. The Group is also committed to reducing emissions from its purchased goods and services and investment goods by 25% over the same period". (Teknikum 2023.)

As another sustainability program, Teknikum Oy's opted to the Chemical Industry Federation of Finland's Responsible Care, which is the most renowned initiative supporting sustainable development. They state in their sustainability report of 2022 that the rubber compounds do not contain Substances of Very High Concern, stated in a REACH directive, and do not contain heavy metals (Teknikum 2022). REACH is regulation in the EU of chemicals of risk to human and environment health (Europa n.d.)

Teknikum Oy's sustainability agenda includes SMETA (Sedex Members Ethical Trade Audit) 4 Pillar audit, which is the most used auditing system for corporations to recognize the social aspects and working conditions in their supply

chains. The audit conducted for Teknikum Oy autumn 2021 recorded no found observations of concern.

As a first in the industry, Teknikum Oy's TEKNICROSS Rubber Level Crossing element system received a verified Environmental Product Declaration (EPD), which is a thorough life cycle assessment (LCA) with multiple impact categories which are related to the environment. EPD's are standardized and therefore comparable and provide independently verified and transparent documentation of the environmental impacts in the product's life cycle. (SFS-EN 15804 2019.)

### **3.2 Rubber Manufacturing**

The unique properties of plastic compounds and rubbery solid substances, which are called elastomers, make them favourable: the elasticity of a rubber compound is the major factor in the popularity of the substance in various purposes in industry and manufacture. Elasticity means that a rubber compound is able to stretch out and be flexible in a desired way, being able to go back to the original shape, hence the name elastomer. Rubber can easily be attached to metal or textile. The molecular structure of rubber allows for unique properties. (Mark et al. 2005.)

Rubber compounds consist of hydrocarbon chain-like molecules called isoprenes. When numerous isoprenes are attached together in long carbon atom units called chains, they are called polyisoprenes, which are also known as natural rubber (Mark et al. 2005). The molecular structure of isoprene is shown in figure x, and the polyisoprenes can consist of thousands of these in a chain with carbons being the core, or "backbone" of the compound. In these polymer chains, the elastomer's carbons are attached to each other by covalent bonds, which allow the molecules to move more freely without breaking the bonds completely, forming a stretchy substance. Carbon chains have properties of being able to rotate some, allowing for further movement. Covalent bonds are double bonds between atoms, formed when two atoms are sharing outer shell electrons, to achieve a less reactive state called the atomic octet. (Gent 2019.)

To achieve the wanted properties of a rubber compound it needs to undergo a specific manufacturing process. The variables can be the mixture of chemicals in

the rubber mix recipe to add qualities of e.g. oil or heat resistance for the finished product. (Gent 2019.)

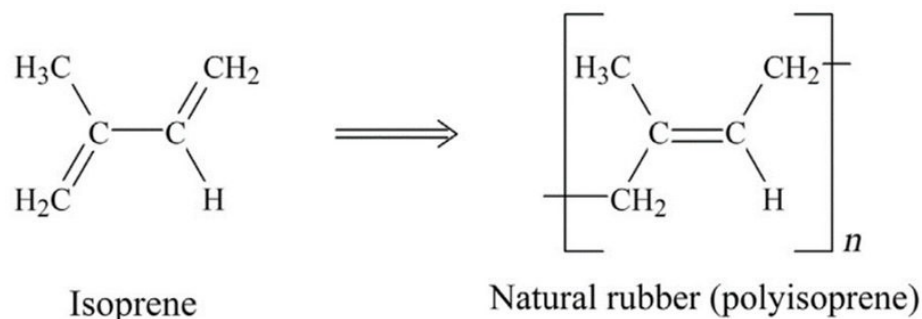


FIGURE 1. Chemical structure of isoprene and natural rubber. (Fazli 2020.)

Natural rubber is produced by certain rubber tree species as their sap, which is a natural latex, and a major ingredient in the rubber industry. There are synthetic versions of rubber with specific properties to sustain wear and tear or/and resistance to certain circumstances, such as temperature, UV light, chemicals and fluids and aging. Synthetic elastomers are made from e.g., fossil fuels (Blaettler 2018).

The basic principle of rubber manufacturing generally consists of four steps. The characteristic of the wanted finished rubber product are tied to the specific process it goes through to achieve them. The steps are compounding, mixing, shaping and vulcanizing. In compounding, the necessary ingredients are added to the raw material rubber to customize it to fit the intended final means of use. Here, chemicals are added to the raw materials, including fillers (often carbon black soot, giving rubber its black colour), silicates, oils, and others. The chemicals will allow the wanted qualities to set when the rubber is vulcanized. Mixing is a delicate process. It means that all the additives are carefully mixed evenly throughout the rubber, as it can be challenging to mix this high-viscosity substance without raising the heat too much. In the last stages of shaping and vulcanizing the rubber products are finalized. Shaping can happen simultaneously with vulcanization. The rubber can be shaped in molds, items can be coated with rubber, or it can be extruded, or many steps of shaping can be taken to come to the final preferred shape. Vulcanization is the addition of some chemical, historically some sulfur,

and heating of the rubber depending on the technique. Vulcanization settles the mix and creates the wanted crossed connections between the polymers (figure 2). Without vulcanization of rubber, the substance would remain soft and sticky when warm and fragile when cold, and the rubber is aging quicker. (Blaettler 2018.)

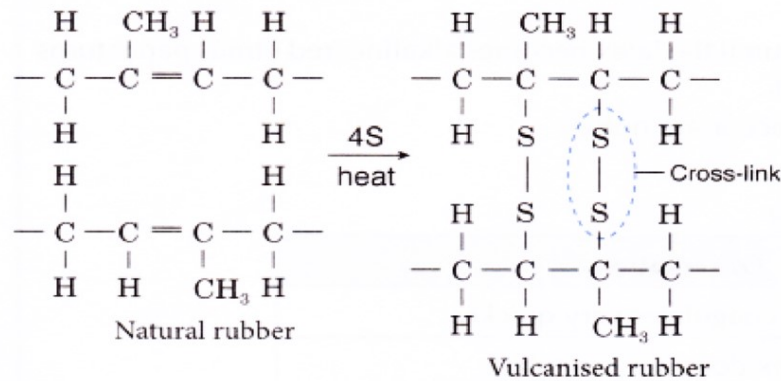


FIGURE 2. An image of the chemical structure of vulcanized rubber showing the web-like linkages between monomers. (Prakash et al. 2022.)

Teknikum Oy has operative plants in Finland and Hungary. In the light of this thesis and the items the tool accounts for, the relevant three plants are located in Finland, in the towns of Kerava, Kiikka, and Sastamala.

In their Kerava plant, the raw rubber mixtures are manufactured but not vulcanized. For some clients, the rubber mixture itself is already the finished product. In these cases, the tool will account for the emissions of raw materials, transport, and energy needs utilized in the making of the mix. Other batches are shipped to other plants for further processing and for vulcanization. For these further processed items, each step is being followed in the tool to ensure that the result accounts for the emissions which are released in the other manufacturing plants.

#### 4 ITEM BASED CO<sub>2</sub>E CALCULATION TOOL

For the SBTi, a GHG Protocol calculation of the overall emissions for the company was conducted. The calculation sheet is the reference for the created item-based emission calculation tool. The scopes and their categories are listed with their relative share of total emissions of Teknikum Oy in table 2.

Emissions by source	Share of emissions (%)
<b>Scope 1</b>	
Fuels	0 %
Self-produced energy	5 %
Refrigerant leaks	0 %
Scope 1 total emissions	<b>6 %</b>
<b>Scope 2</b>	
Electricity	11 %
Heat	1 %
Steam	0 %
Scope 2 total emissions	<b>12 %</b>
<b>Scope 3</b>	
Category 1: Purchased goods and services	<b>53 %</b>
Category 2: Capital goods	18 %
Category 4: Upstream transportation and distribution	<b>2 %</b>
Category 5: Waste generated in operations	1 %
Category 6: Business travel	0 %
Category 7: Employee commuting	2 %
Category 8: Upstream leased assets	1 %
Category 9: Downstream transportation and distribution	0 %
Category 10: Processing of sold products	3 %
Category 12: End-of-life treatment of sold products	2 %
Scope 3 total emissions	<b>82 %</b>
Total	1

TABLE 2. Scopes and their categories included in the GHG accounting of Teknikum in 2020 with their relevant share of total emissions (Teknikum 2022).

Majority of Teknikum's emissions come from the scope 3, which are the other emissions in the value chain apart from direct and self-produced emissions. Category 1: Purchased goods and services, which is the raw materials for the polymers, accounts for 53% of the whole company's emissions (table 2).

#### **4.1 Theory of the Tool**

The products are chemically complex mixtures, with the number of ingredients varying and the production line processes unique to each. The tool follows the emissions in the process from raw materials to finished product. The principal of the calculator is to account for the parts of the process the item goes through in its first stage of life, until it is a finished product, and ready to be shipped to the client. In other words, the tool shall only take into account relevant emissions in those steps of the production process which happen before the product is finished, and therefore this value can be used by the client to add on to their own emission accounting.

The relevant scopes and categories were chosen to be included by the basis of the process; the emissions are accounted for the item itself apart from other operations within the company as a whole, to give the most accurate and useful CO<sub>2</sub>e factor between items. The tool's relevant emission sources by the GHG Protocol are in table 3.

<b>Functional unit</b>	1 kg of item of interest
<b>System boundary</b>	
<b>Scope 1</b>	Self-produced energy
<b>Scope 2</b>	Electricity Steam
<b>Scope 3</b>	Category 1: Purchased goods and services (raw materials) Category 2: Capital goods Category 4: Upstream transportation and distribution Category 5: Waste generated in operations
<b>Result</b>	emission factor (kg CO <sub>2</sub> e/kg of item)

TABLE 3. The emissions sources in the item-based CO<sub>2</sub>e accounting tool as expressed in the original GHG calculation.

This way CO<sub>2</sub>e values, if given to interested outer parties, represent the cradle-to-gate part to that process point. Whereas adding emissions for, e.g., end-of-life possibilities or adding an estimation of the usage lifetime, could lead to uncertainty and errors.

The calculation tool is based on the data collected for GHG Protocol calculation in 2020. The original calculation was done to begin the company's SBTi pathway to be able to reduce emissions in the whole company's processes. There have been more recent calculations since the tool was created.

#### 4.1.1 Raw materials

This section is what the majority of the item's CO<sub>2</sub>e factor is composed of. Raw materials are used in the number of hundreds in the industry, and include for example: natural rubber, synthetic rubber, chemical filler and softener materials, soot, different kinds of plastic compounds, metals, glass, silicone, chemical accelerators, and many others. In the frame of this thesis, it is not necessary to include confidential information of the specifics about the raw materials or the manufacturing process of rubber and polymer itself.

For the accounting of the raw materials, Teknikum Oy's input mix for an item is laid out on the tool. There is a list of CO<sub>2</sub>e factors for about 60 most commonly used raw materials to match and pick out from. Any similar raw materials can utilize a common factor. The list is expanded as more information becomes available and is reported by suppliers.

For the unknowns, there is an average emission factor for the most common raw materials in compounds. If the unknowns are 5-10 % of total item composition by weight, on average, they are given an estimation. This is done due to agreeing on instead of completely not reporting a value for unavailable data, it is given a most accurate estimation by average.

There are GHG's released related to raw material extraction as each material goes through it's own processing. A CO<sub>2</sub>e factor can be given by the supplier and is then based on their estimation of emissions caused by extraction and whichever the processes necessary are to refine the desired material. All of this can include the use of machinery, energy and power, which all cause GHG emissions.

#### **4.1.2 Transport**

Different materials are sourced by various suppliers around the world. Internally, there is transport of materials between plants. In the GHG inventory, which was used as a data source for the tool, all of Teknikum Oy's emissions from transporting goods are collected and can be added up to represent one factor.

The tool gives each item the same value for transport emissions. This is calculated by dividing all transport emissions equally between the total sold item kilograms, from any plant. This was decided to be the most reliable way due to:

- it being too complicated to track each raw material to its origin to serve the functionality of the tool,
- lack of time and resources in figuring out the way of transport,
- the percentage weight that material accounts for in that transfer to derive the share of emissions,
- not all items getting transported internally between plants, which means these sales should be only getting certain emissions from upstream, and

- averaging this value does not have much effect on the overall emissions factor, as transport emissions are a small fraction of the total emissions.

The workload is very major compared to the difference it makes in the overall emission factor, as transport emissions are only 2 % of the total emissions for Teknikum Oy (table 2). A material having shorter shipping distances is losing on its overall factor by a small amount, where as a material with longer distances is benefiting of the average. Overall, choosing to account this way, emissions are not being neglected, as all of the finished products are accounting for all of the transporting emissions.

### **4.1.3 Manufacturing**

Teknikum Oy has systems and software to follow their energy and power usage and generation from providers. The system reports the corresponding CO<sub>2</sub> emissions along the energy used. The data provided is of high quality and can be reported monthly and yearly. For the tool, this relevant data was supplied by the company for each plant individually. It was decided that the tool shall use a yearly average of emissions for the best estimation, as it serves function of the tool well and accurately, not needing to check for each item's manufacturing month.

Manufacturing, as was done in the transport section, was given an average emission factor for each plant, as it was seen the most accurate option. This was done due to:

- not being able to differentiate, which items are being processed and for how long by which machines, as there is no metering differentiating between machinery available
- each item is partly responsible for the energy needed for facility, such as heating, lighting, electrical appliances not straightforwardly linked to manufacturing machines (such as staff computers), staff's quarters and break area, and
- the overall CO<sub>2</sub> values supplied for each plant are of high-quality data and can be reported very accurately.

In giving an average, it is acknowledged, an item that is processed mechanically less is getting more added to its CO<sub>2</sub>e factor, whereas an item that is going through a longer process of mechanical work, is having less added. Overall, this was agreed to be the best and most accurate way of including all the emissions in a relevant way, and it serves the purpose of the tool's functions well.

The tool accounts for the raw material composition's emissions. Then, depending on the number of plants it goes through for processing, the manufacturing emissions for each are added to the value. For each final GWP factor, 10 % of it is added to account for waste and scrap produced during manufacturing. The waste and scrap factor percent is taken directly from the company's process reports and was rounded up to the nearest even number to ensure the reliability of the tool's emission factor remains.

## **4.2 Data sources**

The GHG inventory, which is considered confidential, acted as a major reference for the tool's CO<sub>2</sub>e factors. The factors are originally from emission data banks verified and updated by professionals. For some of the factors and some data comparison, Granta Edupack software was used. Some information was compared using the openCO<sub>2</sub> website.

Manufacturing data is supplied by the energy and power provider of the plants by month. The data includes the use of electricity in kWh and the corresponding CO<sub>2</sub> tonnes, the use of liquefied petroleum gas (LPG) in kilograms and the corresponding CO<sub>2</sub> tonnes, and the total energy used in kWh, and total CO<sub>2</sub> tonnes. This data is specific to each plant. However, the emissions are reported in CO<sub>2</sub> and the other gases equivalent is not known, when it is assumed that there are some other GHG's released in some amounts. Therefore, the values might be just slightly lower than if CO<sub>2</sub>e was reported. In conclusion, scopes 1 and 2 which account for the energy emissions are only about 18 % of the total emissions of Teknikum Oy, so this can be considered data of high quality and accuracy, nevertheless.

## 5 CASE CALCULATION

As a finalising part of the research a piloting emission tool was tested out by the student and the company's representatives. To test out the functionality of the tool, a case calculation was done. The purpose was to evaluate the usability, effectiveness, and reliability of the tool. The tool functions are as explained in this section.

A client had purchased an amount of rubber-based product from Teknikum Oy and requested to know the CO<sub>2</sub>e factor. The client wished to know how the purchase affected their company's emissions in the GHG calculations they initiate for their own processes.

A set factor is already in place for the transport and manufacturing per each plant. To go forward, the CO<sub>2</sub>e factor of the raw materials was calculated. Teknikum Oy got the list of components in their rubber mixture from their enterprise resource planning system, and each was given their respective CO<sub>2</sub>e factor in the tool. For the remaining unknown substances, which were less than 10% of the total weight of the mix, the average was used. From here, the emissions of the raw materials can then be calculated and summed together.

The following step included mapping out the process flow to know which plant's manufacturing factor should be added to the result. When this was done, everything needed was available and the following steps were added together:

1. Raw materials
  2. Transport (average, same for all items)
  3. Manufacturing (average per plant, factors of plants included in the process)
  4. To final result, 10 % of the result added for waste and scrap in production
- Result is reported as kg CO<sub>2</sub>e / kg item.

Before the testing during the earlier research and planning, it was seen as a relatively significant issue that there were many unknowns in the raw material emission data. The raw material chemicals which might be added into different mixes

range from tens to hundreds in variety depending on the product in question. It was then suggested that if the additive or chemical does not account for more than 10 % of the mixture's weight, its emission factor is less significant to the final result. Most of the final factor is comprised of the compounds which are present in higher quantities by mass in the product. The case calculation showed that in using an average (as it is assumed that here will be some emissions present in every activity nevertheless), instead of excluding data completely, it is much more likely to achieve a more accurate emission factor as a result.

Due to the sensitive nature of the calculation data, the details of the calculation are not revealed in this thesis. The case calculation includes data which can be described as confidential. The case accounting was acceptable at prototype level, and it was determined that the chosen scopes and categories represent the cradle-to-gate well and the reason for any possible exclusion or averaging are well justified.

## 6 VALIDITY AND RELIABILITY

As in all LCA's and emission accounting, there are limitations in the quality of the data. Due to the complex nature of the varying polymer product's mixtures, there are unknowns in the raw material data. Raw material composition in industry utilizing chemicals, such as Teknikum Oy, can be of thousands of incoming. To reliably provide CO<sub>2e</sub> factors for the finished item with complex raw material and process mixes, some estimations were done. Not all raw material suppliers are providing emission data for their products at this point, and it is rather uncommon to be able to provide emission data.

In a rubber mixture, the emission factors for the major share of ingredients which have the largest share of the item's weight are known and validated. In the mix, the unknown emission factors are the ones that account for approximately 1-10 % of the whole item; therefore, whatever the emission factor that is missing, the effect on the overall emission factor of the item is relatively small. This is due to the fact that most of the emission factor's value will be represented by the ingredients that the item is mostly comprised of by weight.

The manufacturing processes in plants are given a plant specific average CO<sub>2e</sub> emission value, which remains the same for all produced items. In reality, the different products are manufactured with different machines and others need more processing than some. At the moment of the study, it is not possible to measure individually the energy and power needed to produce individual products. The machinery is not equipped with metering devices for these purposes. The average value is derived from the overall energy consumption of the facility divided with the overall number of product kilograms produced. This was accepted as the most accurate way of accounting emissions for all items at the time of the study. On the other hand, the manufacturing emissions are coming from the energy and power needs in plants, which are only 18 % of Teknikum Oy's total operation's emissions. This is less than a fifth, whereas raw materials account for the majority of the emission factor, and the average can therefore be accepted as the changes would be minimal in any case.

For manufacturing, the emissions are reported in CO<sub>2</sub> and the other gases equivalent is not known, when it is assumed that here are some other GHG's released in small amounts with CO<sub>2</sub>. The CO<sub>2</sub> values might be just slightly underreported than if more gases as CO<sub>2e</sub> were reported. In conclusion, as mentioned before, scopes 1 and 2 which account for the energy emissions are only about 18 % of the total emissions of Teknikum Oy, so this can be considered data of both good quality and accuracy, nevertheless.

When considering the whole environmental approach of e.g. industrial activity, in some cases CO<sub>2e</sub> can be misleading, as there are as many impact categories to meter environmental effects as there are anthropogenic activities. GWP doesn't include other very possibly significant impacts on water and land but focuses on air pollution and global warming. Still, it is commonly accepted in the scientific community, that major issues are caused in the atmosphere and the constant speeding up of global warming are mainly caused because of greenhouse gas emissions. (NASA n.d.)

It is important to follow a standardized procedure when calculating emissions to inventory, as it is a challenge for practitioners to monitor and decide upon the scope of calculations. Within a framework, the studies can be more reliable and even comparable between each other and allow for the target setting and development throughout reporting years. Otherwise, if no general instructions are being followed, one can include and exclude emissions from whichever sources are desired, and the data will only reflect those.

## 7 DISCUSSION

It is the interest of the company, clients, and stakeholders to understand how the GHG emissions are distributed within the company's numerous products. A client purchasing products from Teknikum Oy might be doing their own CO<sub>2</sub>e accounting and reporting, therefore it is convenient to know the emissions of the purchased item and add the CO<sub>2</sub>e to their own calculation. To be able to provide CO<sub>2</sub>e factors acts as a market advantage, environmental approach aside. Sustainability with data backing it up is a growing phenomenon among the world's largest companies, with yearly sustainability reports and participation in SBTi. Sustainable finance and environmental, social, and governance (ESG) practices are more popular than ever and in the expectations of consumers and clients. (Winston 2022).

The SBTi offers a concrete and standardized action plan for reducing emissions and target-setting, which are based on the up-to-date, cross-referenced science. It is necessary to empower this kind of voluntary pathways to emission reductions, as it shows how to reach the targets instead of just setting them. As in Teknikum Oy's case, it is most likely that most of any company's emissions lay heavily in scope 3 (table 2). These are the indirect emissions which were released to make the production of that product possible, and anything that is required to consume the product. As most of the impacts are likely to be outside the direct activities of a company, it is of great importance to account for those activities. To collect emission data for scope 3 is a great workload, and for Teknikum Oy, large amounts of data was collected for e.g. the raw material emission factors from supply chain deliverers and data banks.

As expected, there are limitations in the data available, meaning it is difficult to derive the different emission fractions in production and in raw materials. The supply chains are far-fetching, and factories produce multiple chemically complex products which require thermal energy and mechanical energy. Emission accounting and reporting are fairly new practices in industry: emission monitoring and reporting required by the EU from each nation's activities, including industry, became mandatory around 2013 (European Commission n.d.).

The tool provides an item-specific kgCO<sub>2e</sub>/kg value representing its impact on global warming. This value accounts for the parts of Teknikum Oy's processes to the step of finished product. A stakeholder or client might request to know these specific values of emissions to account for their own emission scope 3, which includes purchased goods. If doing so, there is a possibility that emissions are being counted double. As Teknikum Oy is participating in SBTi and has committed to emission reductions, the company will continue to regularly assess their total emissions. It is not in the research of this thesis and in the tool's function, whether in their following GHG inventories the tool could provide a means of preventing of such issue. Produced and sold goods are accounted for as their own emissions in their relevant scopes as normally. At the point of purchase, it can be argued whether the emissions are shifting to the buyer or whichever entity obtaining the item, or whether it is accepted to include the emissions by both entities in their calculations. In the framework of this thesis and in building the tool, the system boundary was set to not acknowledge double accounting, nor it is considered in any particular step. However, it is understood that there is a need for further research about this issue, and to avoid false emission trading and double counting, the issue should be acknowledged.

Another issue with the polymer industry is the raw material. There are destructive impacts in extraction, such as deforestation, as mono-crops of rubber plantations destroy ecosystems due to unsustainable agricultural practices (Batten et al 2021). Mono-crop means that instead of a variety of species that would occur in an area naturally, only one type of plant is being planted and farmed. Mono-crops make the biodiversity poorer and less organisms favour these environments. At Teknikum Oy, chemists are working in research and development team to find suitable mixtures of natural and fossil rubber to sustain the industry and make the impact on the environment smaller.

It is in the rubber industry's main interest to maintain, preserve and grow the supply of natural rubber in the future. Therefore, purchasing natural rubber from suppliers with Forest Stewardship Council (FSC) certification can provide an alternative to sustainable development along with the emission reduction targets. The rubber tree farming is a challenging activity also in many other sustainability aspects apart from environmental, such as fair pay of workers and ethical working

conditions. However, it needs to be considered whether obtaining certificated raw materials serves the quality management and economical aspect. (FSC n.d.)

However, there is some carbon sequestration in action, when farming any biomass. Therefore, it can be argued that natural rubber plantations act as carbon sinks. Unfortunately, tree-planting on its own is not seen as a sufficient means of offsetting emissions, as there physically isn't enough space in good-quality soil for enough trees to even offset a fraction of the yet-to-peak growing emissions. Tree planting has been seen as a great way to bind carbon to the trunks as biomass, but even if all the space possible was used for tree planting, there just wouldn't have enough time – the emissions need to start reducing quick and it is not a possibility to wait 10-30 years for the trees to be matured and in full carbon sequestration action. (Innovation News Network 2022.)

Due to the crop locations, there are concerning human rights issues, and there can be large holes in the knowledge of supply chains in the raw material production of rubber. CO<sub>2e</sub> value also does not give any impression of other relatable environmental threats present in both farming of the rubber tree and extracting the crude oil for polymer, such as land erosion, biodiversity loss due to monocrops, and clearing of rain forests. (FSC n.d.)

To combat climate change, energy and raw material derived from fossil fuels need to shift to renewable solutions. This is an obvious challenge for a polymer industry such as Teknikum Oy among many. In the plants located in Finland, electrical energy needs are very likely to be filled with a larger fraction of renewable energy production in the future, as Finland is getting more wind energy parks. In Finland, it is estimated that about 30 % of used energy will be produced with wind energy in the next decades compared to 10 % in 2020 (ELY n.d.). This, as an example, gives a larger and more economical opportunity for industries to purchase green energy for their manufacturing facilities.

The relevance and importance of an item-based emission accounting tool is especially large in a polymer industry as there are not many changes that could be made to the manufacturing process, including the choice of raw materials, without compromising the unique properties and needed qualities of the finished rubber

product. To obtain the web-like chemical structure the process needs to be quite specific and does not allow for many changes. This is what can make it very challenging for such industry to make changes as the quality of products cannot be negotiated, and high-quality, safe produce with excellent properties are vital values for the company. The tool can give an insight of where there could be possibilities to design changes in production and where the largest impacts are, and whether any changes to reduce emissions are feasible to do. In an industry such as Teknikum Oy, even a small adjustment could lead to emission reductions. The careful following of complexity of chemistry and process flow are needed to obtain the characteristics of a desired final product.

During the study it was realized that as a filler material to the rubber mixtures, chalk (calcium carbonate) is a possible low-emission option for production compared to soot. According to Granta Edupack software, chalk has a low GWP value of about 0,02 kg CO<sub>2</sub>e/kg, whereas according to the GHG Protocol calculation, soot has a significantly higher GWP value of 2,37 kgCO<sub>2</sub>e/kg. However, not all products allow for such changes without changing necessary properties of the finished product.

In the origin data set, natural rubber was given a GWP factor of 0,67 kgCO<sub>2</sub>e/kg. Granta Edupack software, which was utilized in this thesis and is supplied to students by the Tampere University of Applied Sciences, includes material datasets with their respective CO<sub>2</sub>e factors. In Granta, natural rubber is given a higher value of about 2,0 kgCO<sub>2</sub>e/kg. It was preferred to go with the original factor as the company's SBTi calculation was developed with this value, but it is important to note that the factors can vary between data sources. As natural rubber is extracted from farmed trees, which are a carbon sink on their own, it can be challenging to address the trees lifetime and the carbon capture in it's lifetime to the produced rubber and finally be able to demonstrate the GWP value accordingly. A typical rubber tree's lifetime is approximately 30 years (FSC n.d.). It is essential, for these reasons, to accurately report sources of emission factors.

The GHG calculations are still today rather new to industry, and the standards are being developed for more transparent, accurate, comparable, and reliable

emission accounting. Anything related to emission accounting should be approached with criticism and awareness and transparent reporting has to be done. Both resources and workforce are used to collect any CO<sub>2</sub>e factors and data, which are needed in large quantities, and in comparing them. It also isn't often economically viable for companies to obtain, e.g., an EPD for their product, which is a strictly standardized, protocol following method of assessing a product's environmental impacts in many categories, as it can take months of work and research for parties conducting them. Due to the uniqueness of any organizations processes, there is a very complex nature in LCA and emission accounting. Utilizing consultants who are able to follow a certain standard can allow for reliable, cross-referenced emission accounting.

## 8 CONCLUSION

A calculation tool was created to assess the GWP of a product. The calculator accounts for the lifecycle steps the product goes through to the point of sending the finished product to client. The calculator gives, to the best available knowledge, a CO<sub>2e</sub> factor value to an item, and this is the best available estimation of the product's GHG emissions as based on the company-wide GHG inventory. Calculator was designed to be updated easily with new emission data as SBTi follows the GHG Protocol and data to be yearly updated. The functionality of the tool was seen fit to Teknikum's processes.

Calculator uses an average value for transport and manufacturing. The original manufacturing data is of high quality and the emissions can be calculated specifically per year. Due to the complex nature of the production process, it is the best estimation to divide these GWP values equally to each produced item kilogram. Raw material extraction for the products accounts for over half of the total emissions of the company, so this sector is where the differences in the product's CO<sub>2e</sub> values are. The tool can be a useful source for decision-making in reducing emissions and can provide CO<sub>2e</sub> factors of individual items for entities requesting them.

Reducing the use of fossil fuels in all operations and committing to best available, eco-certified raw materials are the major ways to cut emissions for Teknikum Oy. For future research it is suggested that the possible double accounting of emissions is acknowledged as a possibly occurring issue and whether it would be feasible to obtain the use of certified natural rubber without excessive economical changes and without compromising excellent product quality.

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**APPENDICES**

Appendix 1 (Classified). Item Based CO<sub>2</sub>e Calculation Tool

Appendix is classified due to corporate confidentiality.