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Second Cycle, 30 credits

Sustainable Process Changes

A Comparative Carbon Footprint Analysis of Biogas Utilisation Scenarios and
Development of Educational Measures for Enhanced Sustainable
Corporate Decision-Making

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**Sustainable Process Changes: A Comparative Carbon Footprint
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Educational Measures for Enhanced Sustainable Corporate
Decision-Making**

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Abstract

According to the latest report by the Intergovernmental Panel on Climate Change, anthropogenic greenhouse gas emissions unequivocally contribute to global warming, and reductions of greenhouse gas emissions in the industrial sector can be achieved through strategies such as optimising material flows. Furthermore, employees' perceptions of, and approaches to, sustainability are crucial for shaping a comprehensively sustainable organisational culture. The aim of this study is to assess the potential differences in carbon footprint for two utilisation scenarios of biogas produced at the Swedish biorefinery Domsjö Fabriker. The first scenario involves internal utilisation of the biogas at Domsjö Fabriker and the second scenario involves upgrading, distribution, and external utilisation of the biogas as vehicle gas. Furthermore, the aim is to identify what educational measures can be implemented to enhance sustainable decision-making. A single-issue life cycle assessment showed that there is potential to reduce the carbon footprint by upgrading, distributing, and utilising the biogas as liquefied vehicle gas, as opposed to utilising the biogas internally. Interviews with employees regarding sustainability efforts at Domsjö Fabriker, followed by a thematic analysis, showed that it is possible to enhance an ecocentric management within the company. Educational measures, aiming to enhance ecocentric reasoning within the organisation, were suggested based on a framework for transformative learning. The result of the carbon footprint analysis was discussed in terms of uncertainties in data collection, economic incentives and alternative technical assumptions. The suggested educational measures were discussed based on aspects such as validation.

Keywords

Ecocentric management, carbon footprint, biogas utilisation scenarios, liquefied biogas (LBG)

Sammanfattning

Enligt den senaste rapporten av Förenta nationernas klimatpanel bidrar antropogena växthusgasutsläpp otvivelaktigt till global uppvärmning och minskningar av växthusgasutsläpp inom industrisektorn kan uppnås genom strategier såsom optimering av materialflöden. Vidare är anställdas uppfattningar om, och tillvägagångssätt till, hållbarhet avgörande för att forma en heltäckande hållbar organisationskultur. Syftet med denna studie är att bedöma potentiella skillnader i koldioxidavtryck för två användningsscenarier av biogas producerad vid det svenska bioraffinaderiet Domsjö Fabriker. Det första scenariot innebär intern användning av biogasen på Domsjö Fabriker, medan det andra scenariot innebär uppgradering, distribution och extern användning av biogasen som fordonsgas. Vidare är målet att identifiera vilka utbildningsinsatser som kan genomföras för att förbättra hållbara beslut. En livscykelanalys med avseende på utsläpp av koldioxidekvivalenter visade att det finns potential att minska koldioxidavtrycket genom att uppgradera, distribuera och använda biogasen som flytande fordonsgas jämfört med att använda biogasen internt. Intervjuer med anställda om hållbarhetsarbetet på Domsjö Fabriker, följt av en tematisk analys, visade att det är möjligt att förbättra ett ekocentriskt ledarskap inom företaget. Utbildningsåtgärder, med syfte att förbättra ekocentriskt resonemang inom organisationen föreslogs baserat på ett ramverk för transformativt lärande. Resultatet av koldioxidavtrycksanalysen diskuterades med avseende på osäkerheter i datainsamling, ekonomiska incitament och alternativa tekniska antaganden. De föreslagna utbildningsinsatserna diskuterades baserat på aspekter såsom validering.

Nyckelord

Ekocentriskt ledarskap, koldioxidavtryck, scenarier för biogasanvändning, flytande biogas (LBG)

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1 Introduction

According to the latest report by the Intergovernmental Panel on Climate Change (IPCC), anthropogenic emissions of greenhouse gases have unequivocally caused global warming, with a global surface temperature of 1.1°C above the 1850–1900 levels in 2011-2020 (Calvin et al., 2023). In 2019, approximately 79% of global greenhouse gas emissions came from the sectors of energy, industry, transport, and buildings combined, while agriculture, forestry, and other land use accounted for 22%¹ of these emissions. In order to mitigate climate change and limit global warming, Sweden has agreed to international commitments such as the Paris Agreement, in which all participating countries strive to limit the increase of global temperature (Paris Agreement, 2015). Limiting the rising global temperature necessitates significant mitigation of greenhouse gas emissions, particularly within the sectors where those emissions are most substantial. To address the challenge of reducing industrial emissions, the IPCC claims that reductions in greenhouse gas emissions can be achieved through, for example, resource efficiency and circular material flows (Calvin et al., 2023).

Domsjö Fabriker, situated in Örnsköldsvik in northern Sweden, is a biorefinery specialising in refining raw materials derived from softwood into various bio-based products (Domsjö Fabriker, n.d.). Additionally, Domsjö Fabriker produces biogas from volatile biomass residues as a by-product, currently utilised for internal processes. Due to surplus production, some of the biogas is currently flared, meaning not all energy is utilised. By enhancing circularity and resource efficiency of raw materials and energy, Domsjö Fabriker has the potential to reduce ecological impacts while benefiting from the natural circularity of carbon, hence aligning with the objectives outlined by the IPCC. As part of Domsjö Fabriker's efforts to increase circularity and resource efficiency, the company aims to explore the potential in upgrading and distributing their biogas as vehicle gas. This assessment involves evaluating the carbon footprint associated with different utilisation scenarios of biogas.

Potentially altering the biogas utilisation requires decision-making regarding process changes. According to Linnenluecke and Griffiths (2010), perceptions of, and approaches to, sustainability within the organisation are critical in shaping the organisational sustainability culture. How employees involved in a process change reason about sustainability thus can be crucial in shaping the direction and outcome of such changes. It is therefore relevant to examine how employees

¹According to Calvin et al. (2023), GHG emission levels are rounded to two significant digits. Due to this rounding, differences in the sum may occur.

involved in the potential process of biogas change at Domsjö Fabriker reason about sustainability, and, based on this, develop suggestions for educational measures aiming to enhance sustainable decision-making within the organisation. By assessing the carbon footprint of biogas utilisation scenarios and developing suggestions for educational measures, this study therefore intends to provide a foundation for future sustainable decision-making within Domsjö Fabriker.

1.1 Aim and Research Questions

The aim of this study is to assess the potential differences in carbon footprint for two utilisation scenarios of biogas produced at the Swedish biorefinery Domsjö Fabriker. The first scenario involves internal utilisation of the biogas at Domsjö Fabriker and the second scenario involves upgrading, distribution, and external utilisation of the biogas as vehicle gas. Furthermore, the aim is to identify what educational measures can be implemented to enhance sustainable decision-making.

The research questions to be answered in this study are:

- What is the carbon footprint associated with internal utilisation of self-produced biogas at Domsjö Fabriker?
- What is the carbon footprint associated with upgrading, distribution, and utilisation of the biogas as vehicle gas?
- How do employees, involved in the potential biogas process change, reason about sustainability efforts at Domsjö Fabriker?
- What educational measures can be implemented to enhance sustainable decision-making at Domsjö Fabriker?

2 Background

This study is built upon a selection of frameworks, concepts and previous research, related to vehicle gas, sustainable development, and education for sustainability.

2.1 Biogenic Vehicle Gas

According to Klackenberg (2024) at Swedish Gas Association, there is an increasing use of biofuels in Sweden, including biogenic vehicle gas. A difference between combustion of fossil fuels and biofuels is that the latter results in biogenic carbon dioxide emissions. Biogenic carbon dioxide originates from organic matter and has therefore recently been absorbed from the atmosphere (Bacovsky et al., 2022). Hence, biogenic carbon is part of a cyclic process. An increase in the use of biogenic

vehicle gas therefore has the potential to reduce net greenhouse gas emissions in the transportation sector, as it potentially can replace the consumption and combustion of fossil fuels. For biofuels to be considered environmentally beneficial, Khanna et al. (2011) emphasise the necessity of using sustainably produced biomass. This is crucial due to the impact of emissions related to land use change, which can lead to greater emissions than the direct greenhouse gas savings from biofuel production and liquid fossil fuel substitution.

Biogenic vehicle gas can be in the form of compressed biogas (CBG) or liquefied biogas (LBG), where LBG has higher energy density (Bauer et al., 2013). CBG is mostly used for passenger cars, light trucks and buses, and LBG has a larger market in heavy transport and shipping (Tekniska verken, n.d.). There are currently different networks for distribution of vehicle gas centralised in the southern part of Sweden (Swedish Energy Agency, 2022a, 2022b). Therefore, transportation of both CBG and LBG to filling stations are also common by road transport (Klackenberg, 2024). Producing CBG and LBG requires upgrading the biogas to increase the methane content to approximately 97% (Bauer et al., 2013). During the upgrading process, the gas is generally pressurised and a large amount of the carbon dioxide, as well as other unwanted compounds, are separated from the raw gas (Hjort & Bigelius, 2014). Upgrading biogas to vehicle gas can be performed using different methods, such as water scrubber, pressure swing adsorption (PSA) and membrane separation. To prevent methane leakages from the upgrading process, a complementary catalytic oxidizer can be implemented, in which around 95 % of the methane content in the off-gas is converted to carbon dioxide (Gustafsson et al., 2020).

Producing LBG requires polishing and liquefying the upgraded gas (Bauer et al., 2013). During the polishing process, the concentration of carbon dioxide is reduced to further increase the methane content to 98% or more. The polishing step is usually done using PSA technology. Liquefying the gas involves exposing it to very low temperatures in a refrigerant cycle. There are various refrigerant cycles available, suitable in different contexts. In small and medium scale production, the Brayton refrigeration cycle, using nitrogen or methane as working fluids, is often used (Roberts et al., 2015).

2.2 Frameworks for Sustainable Development

Sustainable development includes ecological, social, and economical dimensions, aiming to achieve environmental quality, social equity, and economic prosperity for both current and future generations. There is no single consensus in academia on how to address sustainability, leading to several perspectives on achieving sustainable development (Bacovsky et al., 2022). One framework for addressing global sustainability challenges is the United Nations' Sustainable Development Goals

(SDGs) (United Nations, n.d.). The SDGs provide a comprehensive framework that considers every dimension of sustainability. However, Rockström et al. (2009) claim that sustainability strategies are characterised by an anthropocentric perspective that focuses on the needs of humankind while deprioritising the ecological effects. At the same time, an agreement is rising among scientists and environmental specialists that human well-being depends on the health of the biosphere and its ecosystems (Calvin et al., 2023; Coutts & Hahn, 2015). One example of a framework that concretises the relevance of ecological prosperity is the planetary boundaries (Rockström et al., 2009). The planetary boundaries identify nine primary processes and thresholds within the biophysical Earth system and, according to Rockström et al., staying within these thresholds prevents irreversible environmental degradation and maintains a healthy planet for human development and well-being.

According to Imran et al. (2014), there is a growing consensus regarding the need for a shift in the ethical stance towards nature and redefinition of the relationship with the environment to foster sustainable development, adopting a more comprehensive and holistic ethical perspective. This holistic approach is prominent in ecocentric ethics by acknowledging the intrinsic and moral value of nature and its ecosystems, therefore challenging the anthropocentric origins of sustainable development by prioritising the well-being of ecosystems alongside human welfare (Imran et al., 2014). The ecocentric perspective emphasises the interconnectedness and interdependence of all elements within ecosystems and highlights the importance of preserving these relationships for the well-being of the planet.

2.3 Ecocentric Management

Ecocentric management highlights the necessity for a shift in how organisations interact with the natural environment, emphasising the importance of introducing approaches that prioritise ecological factors in organisational decision-making (Araujo et al., 2021). Many researchers have contributed to the vision of ecocentric management. Araujo et al. (2021) present a compilation of characteristics of ecocentric management based on several studies. Furthermore, the authors present six ecocentric management concepts, each highlighting different forms of reasoning. The authors argue that these concepts are part of a continuous reasoning cycle, fostering organisational behaviours where sustainability responsibilities and initiatives are fully integrated into strategy, operations, and routines, thus addressing sustainability at a corporate level. Araujo et al. claim that this integration ultimately promotes the long-term sustainability of the company and its alignment with the SDGs.

The six concepts of ecocentric management presented by Araujo et al. (2021) are *materiality*, *uniqueness of place*, *embeddedness*, *sense of place*, *ecological sensemaking* and *radical reflexivity*. Below is an outline of the concepts based on the authors' compilation.

Materiality

Materiality highlights the importance of considering nature and place as stakeholders in decision-making regarding organisational activities. It also emphasises how organisational actions are influenced by the understanding of and engagement with the physical environment. Lastly, the concept of materiality shifts from the view of nature and place being merely an object shaped by humans, to viewing it as an essential stakeholder intertwined with human society.

Uniqueness of place

This concept aims to highlight the importance of recognising and valuing the individuality of each place to be able to better preserve its diverse cultural, ecological, and social aspects. This is possible by addressing all three dimensions that define any place: its location, its characteristics, and its importance to people.

Embeddedness

Embeddedness refers to the acknowledgement of the interconnectedness of humans and their surroundings, recognising that interactions occur within a network of relationships and are influenced by social, ecological, and spatial contexts. Furthermore, it highlights the importance of understanding organisations as inseparable from their social and ecological contexts to foster a more holistic approach to environmental management.

Sense of place

This concept refers to the organisation's connection to a specific location and the feelings of identity, care and responsibility towards the local community and environment. Building a sense of place aims to foster a deeper relationship between humans and environment, resulting in more ecocentric sustainable practices.

Ecological sensemaking

Ecological sensemaking refers to the understanding of material landscapes and ecological processes within organisational activities. It also aims to highlight the acknowledgment of environmental cues and recognising their significance in past and present contexts. Organisations that are embedded in

local ecologies have greater opportunities for ecological sensemaking, enabling them to better understand and address changing ecological conditions.

Radical reflexivity

This concept involves questioning, challenging and critically examining deeply ingrained assumptions, beliefs and practices regarding organisational activities. It also emphasises the individual and collective responsibility to act in ways that foster environmental sustainability. Organisations that continuously evaluate their actions are considered to better understand their impact on society, nature, and place.

2.4 Transformative Learning

To address current global sustainability issues, there is a need for education for personal transformation (Wamsler, 2020). To change existing attitudes, assumptions, and behaviours, Wamsler (2020) argues the engagement in individuals' inner dimensions and capacities through deep reflection on cognitive and socio-emotional processes, thus advocating a transformative learning approach. According to Mezirow (2009) transformative learning is the process of transforming people's problematic frames of reference, aiming to make their perceptions and actions more inclusive, reflective, insightful, open and emotionally able to change. Transformative learning can be summarised as a process of deep personal and intellectual growth that leads to a more nuanced understanding of oneself and the world. Mezirow claims that a main component of transformative learning includes critical reflection of both our own and other's assumptions, examining their source, nature and consequences. Another crucial aspect is engaging fully and openly in discourses where different perspectives and opinions are exchanged in a constructive manner. This approach aims to challenge our own assumptions and deepen our understanding of complex issues, resulting in more informed and reflective conclusions. The educational approach in a transformative learning paradigm is learner-centred, participatory, and interactive (Mezirow, 1997). This approach encourages learners to engage in issues in the context of their personal experiences through activities such as group deliberation, group work, and case studies, aiming to foster collective critical assessment of the justification behind new knowledge.

3 Method

Due to the dual nature of this study's objectives, two separate methodologies were employed to address the research questions. For the carbon footprint analysis, a life cycle assessment (LCA)

methodology was applied. For the development of educational measures, interviews were conducted, followed by a thematic analysis and construction of suggestions for educational measures.

3.1 Carbon Footprint Analysis

To conduct carbon footprint analysis, a single-issue gate-to-grave life cycle assessment methodology, based on ISO 14040 and 14044, was applied (Swedish Standards Institute [SIS], 2006a, 2006b).

Performing an LCA entail assessing the environmental impact of a product, process, or service throughout its whole, or part of its, life cycle. The main goal of the LCA in the present study was to compare the carbon footprint between two different scenarios of biogas utilisation. The carbon footprint was calculated and presented based on guidelines in ISO 14069 and included direct emissions and energy indirect emissions (Swedish Standards Institute [SIS], 2013). A delimitation made in this study was to exclude emissions generated by land use changes.

Life cycle assessment methodology is iterative (Swedish Standards Institute [SIS], 2006b).

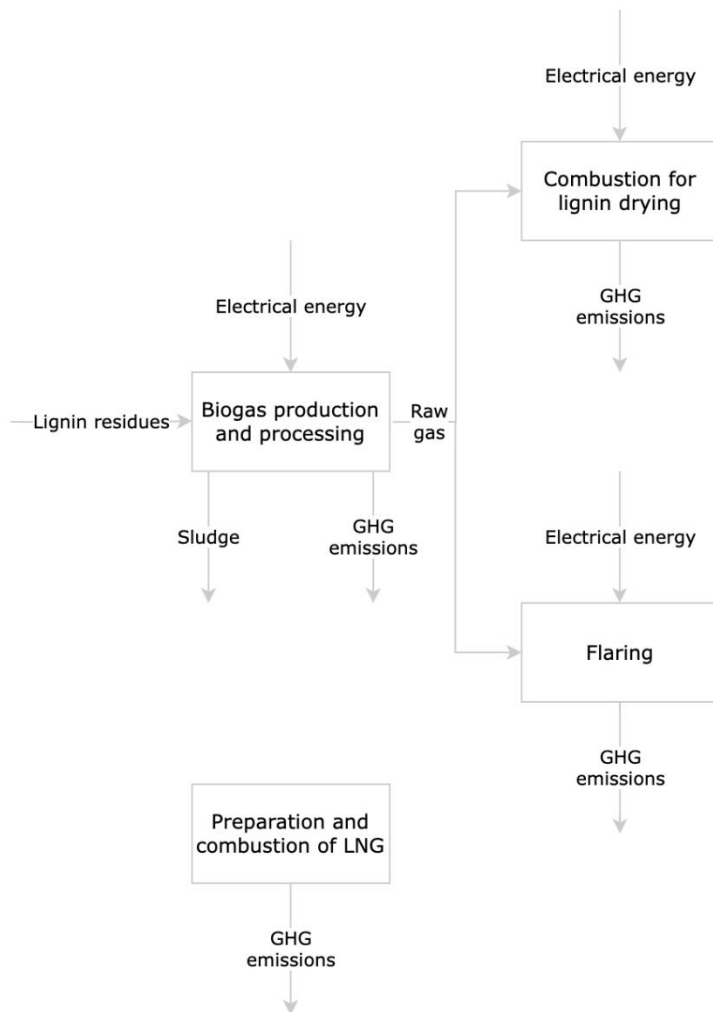
Assumptions regarding system boundaries, processes and data were thus adjusted continuously. To obtain precise results, data collection was modified to include process specific attributes, considering for example context and characteristics. Calculations of energy flows, electricity consumption and emissions were conducted manually. Formulas used in calculations are shown in Appendix A. The primary function of the studied systems is to generate energy for the operation of different processes. The functional unit was therefore set to megajoules (MJ) of energy recovered. The annual carbon footprint of the studied systems was also provided to enable an additional analytical perspective.

3.1.1 The Studied Scenarios

The processes of biogas utilisation were divided into two scenarios: the current scenario and a potential scenario. As this study aims to investigate the differences in carbon footprint between the two scenarios, the initial gate (start of the LCA) for both scenarios were set before biogas production, specifically at the anaerobic digestion, and the final gate (end of the LCA) was set after utilisation of the biogas. Scenario 1 (S1) involves internal utilisation of self-produced biogas to operate lignin dryers and scenario 2 (S2) involves biogas upgrading and distribution for external utilisation as LBG. Schematic overviews of the modelled scenarios are shown in Figure 1 and Figure 2.

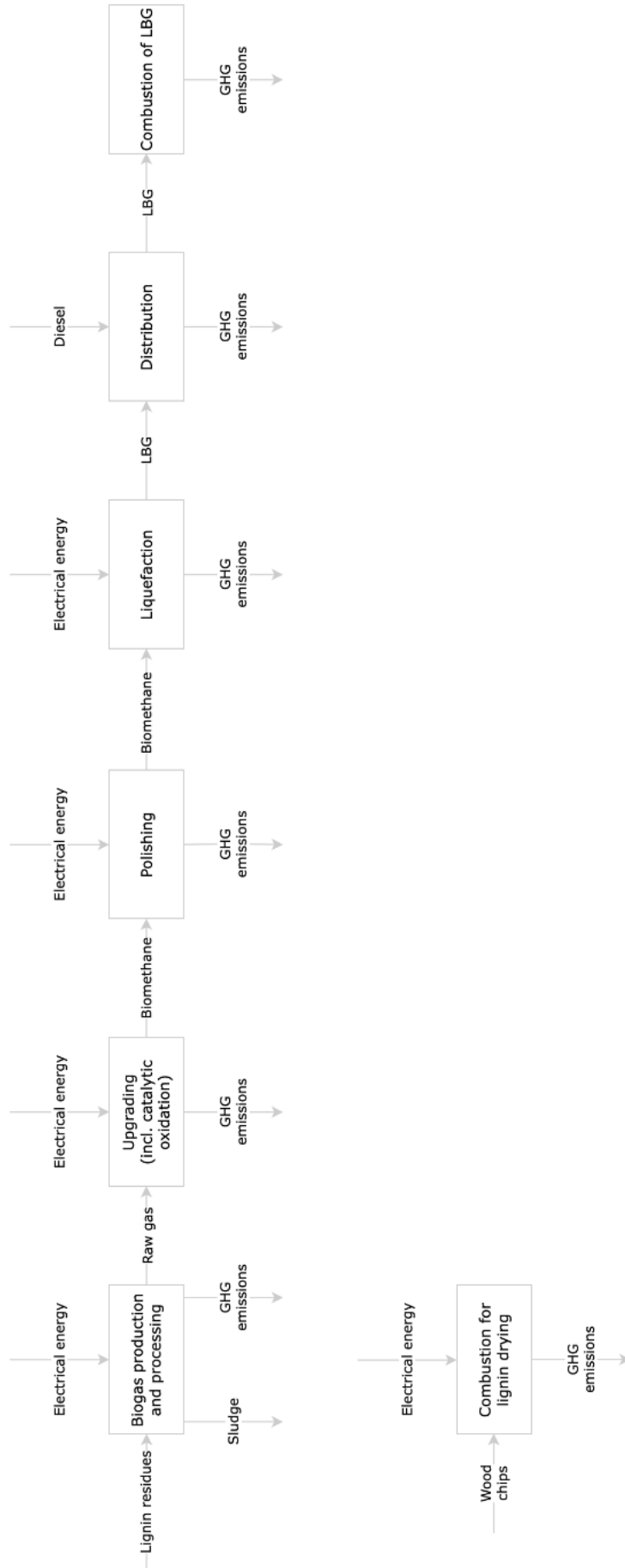
Figure 1

Schematic Overview of Scenario 1



S1 primarily includes biogas production and processing, raw gas combustion for the operation of lignin dryers, and flaring of excess raw gas. Biogas production and processing involves anaerobic digestion, initial scrubbing, sedimentation, and extraction of sludge. To account for the fossil emissions that are replaced with biogenic emissions in S2, S1 additionally consist of life cycle emissions of liquid natural gas (LNG) equivalent to the amount of energy that the biogenic vehicle gas produced in S2 can replace. On-site transport was excluded in both S1 and S2. A small portion of the biogas produced at Domsjö Fabriker is, in S1, supplied to an external actor, and steam produced at the external actor is to a small extent utilised at Domsjö Fabriker. This was however neglected in both S1 and S2, as suggested by Domsjö Fabriker.

Figure 2
Schematic Overview of Scenario 2



S2 includes biogas production and processing as in S1, internal wood chip combustion for the operation of lignin dryers, biogas upgrading with membrane separation, biogas polishing, biogas liquefaction with Turbo-Brayton refrigeration, LBG distribution by road, and LBG combustion in heavy duty vehicles. Any externally produced biogas that may potentially be liquefied and distributed by Domsjö Fabriker was not included. Wood chip combustion was included in S2 as it substitutes the energy supply for the lignin dryers. Wood chip combustion was not included in S1, even though the wood chip used in S2 is combusted at a local external actor in S1. Including the external combustion in S1 necessitates including an alternative energy source utilised by the external actor in S2, and due to vague access for reliable data regarding energy and biomass flows within the external actor, the analysis overlooked all considerations regarding the external actor, hence excluding wood chip combustion in S1. Storage of LBG at Domsjö Fabriker were excluded. The distribution of LBG includes transportation from Domsjö Fabriker to the filling station, and fuelling. Any additional processes related to distribution, such as keeping LBG refrigerated and storing, were excluded.

The assumptions of suitable upgrading and liquefaction technologies were made based on a comparable Swedish industry, with similar energy production size and feedstock (Air Liquide, n.d.; Larsson, 2020). Upgrading the biogas using membrane separation also allows for separation of H₂S (Bauer et al., 2013), which was requested by Domsjö Fabriker. Furthermore, it was assumed that catalytic oxidation will be used to mitigate emissions from the upgrading process (Gustafsson et al., 2020). The assumption to produce LBG instead of CBG was made based on an increased national market and suitable transportation options (Klackenberg, 2024; Statistikmyndigheten SCB, 2024). Transportation of LBG from Domsjö Fabriker to the filling station was assumed to be carried out by diesel trucks. Furthermore, the LBG was assumed to be used in road transportation with heavy duty vehicles, given the increasing national demand for LNG and LBG (Klackenberg, 2024).

3.1.2 Data Collection

Data used in modelling and calculations were obtained through communication with Domsjö Fabriker and literature review.

Data of flows in S1 and S2:

- Raw gas production was set to 60 GWh/yr (H. Grundberg, personal communication, March 18, 2024). The raw gas volume was calculated to 8 020 000 Nm³/yr, which is shown in Appendix A.

- The given raw gas composition was approximately 75 vol.% CH₄, 25 vol.% CO₂, and 0.5 vol.% H₂S (H. Grundberg, personal communication, March 18, 2024). The amount of H₂S was neglected in calculations of carbon dioxide equivalent emissions.
- In S1, the proportion of raw gas combusted for the operation of lignin dryers was set to 65% and the proportion to be flared was set to 35% (H. Grundberg, personal communication, March 18, 2024).

To account for the global warming potential (GWP) of gases, standardised factors from ISO 14069 were used (Swedish Standards Institute [SIS], 2013). Applied factors are shown in Table 1.

Table 1

Global Warming Potential (GWP) for Included Gases

Gas	Factor
CO ₂	1
CH ₄	25
N ₂ O	298

To calculate the carbon footprint of each process of S1 and S2, different methods were applied. A combination of data in terms of standardised emission factors, data of flows (including slippages) and energy consumption were used. Emission factors and additional data are shown in Table 2. Description of assumptions made for data collection are shown in Appendix B.

Table 2*Data Used in Calculations*

Quantity	Value	Unit
Emission factor electricity utilisation Sweden ¹	26.0	g CO ₂ e/kWh
Emission factor LNG life cycle ²	74.5	g CO ₂ e/MJ
Emission factor biogas production and processing ³	42.8	g CO ₂ e/MJ
Emission factor raw gas stationary combustion ⁴	93.0	g CO ₂ /MJ
	0.001	g CH ₄ /MJ
	0.0001	g N ₂ O/MJ
Emission factor wood chip combustion ^{4,5}	89.9	g CO ₂ /MJ
	0.011	g CH ₄ /MJ
	0.005	g N ₂ O/MJ
Emission factor diesel MK1 combustion ⁶	66.7	g CO ₂ e/MJ
Emission factor LBG heavy duty vehicle combustion ⁷	2.86	g CO ₂ /MJ
	0.00909	g CH ₄ /MJ
Electricity demand lignin dryers ⁸	20	kW
Electricity demand flare ⁹	negligible	
Electricity demand wood chip boiler	0.8	MW
Electricity demand biogas upgrading ^{10,11}	0.25	kWh/Nm ³ raw gas
Electricity demand catalytic oxidation ¹⁰	0.05	kWh/Nm ³ raw gas
Electricity demand biogas polishing ¹²	0.15	kWh/kg LBG
Electricity demand biogas liquefaction ¹³	0.29	kWh/Nm ³ biogas
Electricity demand biogas fuelling ¹⁴	0.0032	kWh/Nm ³ LBG
Methane slippage biogas upgrading ¹¹	0.5	%
Methane slippage catalytic oxidation ¹⁴	5	%
Methane slippage biogas polishing ¹⁴	negligible	
Methane slippage biogas liquefaction ¹³	0.5	%

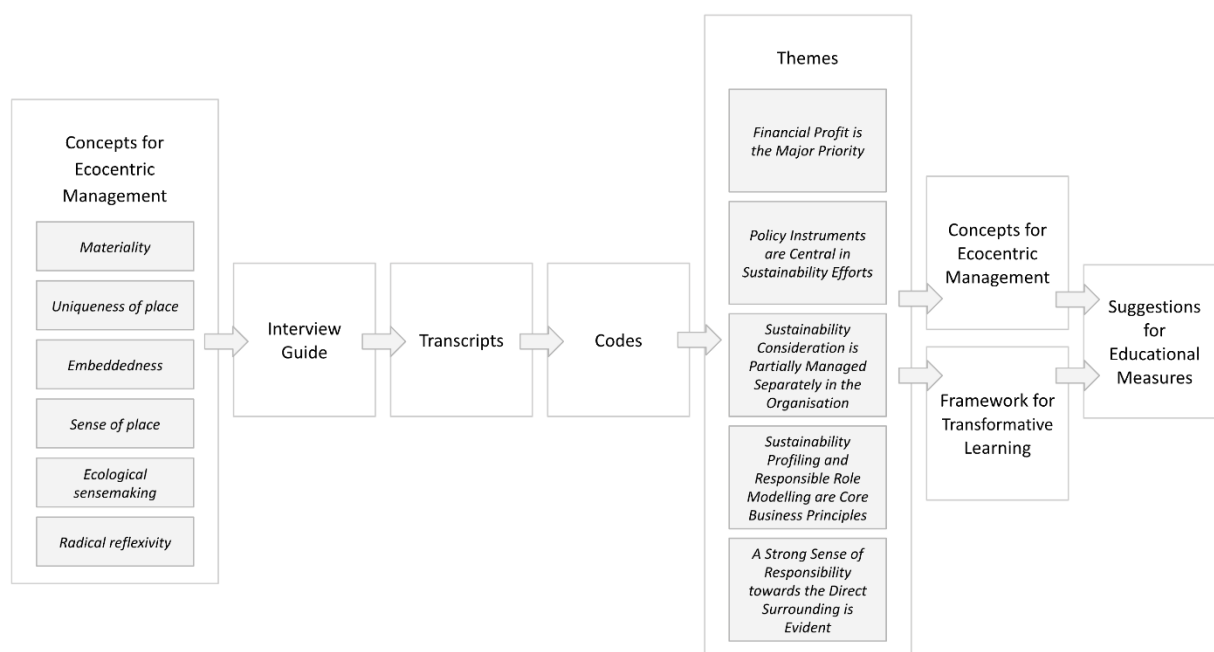
Note. Data from: ¹(Swedish Energy Agency, 2023c); ²(Swedish Energy Agency, 2021a, Table Genomsnittliga normalvärden för växthusgasintensitet under hela livscykeln för fossila komponenter i drivmedel); ³(Swedish Energy Agency, 2021b, Table Disaggregerade normalvärden för biometan); ⁴(Swedish Environmental Protection Agency, 2024a, Table Stationary Combustion); ⁵(Swedish Environmental Protection Agency, 2024a, Table Wood Fuel and Other Biomass); ⁶(Swedish Energy Agency, 2023a, Table 3); ⁷(Swedish Environmental Protection Agency, 2024a, Table Road Transportation); ⁸(H. Grundberg, personal communication, March 18, 2024); ⁹(H. Grundberg, personal communication, March 27, 2024); ¹⁰(Bauer et al., 2013); ¹¹(Hjort & Bigelius, 2014, Table 5); ¹²(Tekniska verken, 2017); ¹³(Air Liquide, n.d.) ¹⁴(Gustafsson et al., 2020).

3.2 Development of Educational Measures

Interviews were conducted to examine how key employees, involved in the potential process change, reason about the company's sustainability efforts in general and in relation to process changes within Domsjö Fabriker. Subsequently, a thematic analysis and interpretation of the interview data was carried out, using the concepts of ecocentric management as a comparative reference. Based on this analysis, and the theory of transformative learning, suggestions for educational measures were developed. In Figure 3, a schematic overview of the methodology for the development of the educational measures is shown.

Figure 3

Schematic Overview for Development of Educational Measurements



3.2.1 Data Collection

The conducted interviews were semi-structured and thus of a qualitative nature, aiming to explore the respondent's opinions and reasoning (Bryman, 2011). A semi-structured interview was chosen as it allows both the interviewer and the respondent to move freely within chosen areas of research. With consideration to the concepts of ecocentric management outlined by Araujo et al. (2021), an interview guide, which is shown in Appendix C, was prepared. The interview guide was then sent to the respondents prior to the interview. Three people were interviewed, and the selected respondents were employees involved in the potential process change of biogas utilisation at Domsjö Fabriker. To highlight several perspectives in the responses, people with different positions

at Domsjö Fabriker were interviewed. The interviews were conducted through video calls and each interview lasted approximately 45 minutes. All conversations were recorded and transcribed. Data to be presented in this report were translated into English.

3.2.2 Data Analysis

A thematic analysis was applied as the data analysis method, following the framework outlined by Braun and Clarke (2022). This method was chosen to systematically identify, analyse, and report themes within the collected data. Initially, a thorough listening and reading of the interview data was conducted to gain a deep understanding of the content. Subsequently, excerpts with central reasoning were identified and labelled into 118 different initial codes. The initial coding was then refined, resulting in 38 different codes. Nine of the initial codes were considered irrelevant and were therefore removed. The remaining codes were then grouped into five initial themes. The themes were reviewed, conclusively defined, and presented together with interview excerpts considered to be relevant to the research question. Central reasoning within each theme was then interpreted using the concepts of ecocentric management as a comparative reference, meaning that reasoning within the themes was interpreted in terms of its alignment with the concepts of ecocentric management.

3.2.3 Construction of Suggestions

Based on the analysis of how key employees in process changes reason about sustainability, and using the concepts of ecocentric management as guidance, suggestions for educational measures were developed with the intention to enhance sustainable decision-making at Domsjö Fabriker. The suggestions were developed within the framework for transformative learning outlined by Mezirow (1997, 2009).

3.2.4 Ethical Aspects

Before the interviews were conducted, an information sheet was sent to all respondents, which is shown in Appendix D. The information was also repeated at the time of the interview. Name, age, gender and position at the company were not included in this report to maintain anonymity. The respondents are referred to as key informant A, key informant B, and key informant C, in no order of priority.

4 Result and Analysis

The results and analyses are presented in three sub chapters. The carbon footprint analysis is presented first. Subsequently, the respondents' current sustainability reasoning is presented, followed by suggestions for educational measures.

4.1 Carbon Footprint of S1 and S2

The result of the carbon footprint analysis is initially presented in relation to the functional unit, which is MJ of energy recovered. In scenario 1 (S1) and scenario 2 (S2), different amounts of energy are recovered. The LBG produced in S2 corresponds to an energy amount of 213 TJ/yr. This can be compared to the raw gas utilised in the lignin dryers in S1, which amounts to 140 TJ/yr. Table 3 shows emissions of carbon dioxide equivalents by process and in total, relative recovered energy in S1 and S2 respectively. The results are presented in total emissions, excluding emissions of biogenic carbon dioxide, and in emissions of biogenic carbon dioxide.

Table 3*Emissions of Carbon Dioxide Equivalents by Process and in Total per Energy Recovered in S1 and S2*

Process	Scenario 1		Scenario 2	
	Total emissions (excl. bio-CO ₂) [g CO ₂ e/MJ]	Bio-CO ₂ emissions [g CO ₂ e/MJ]	Total emissions (excl. bio-CO ₂) [g CO ₂ e/MJ]	Bio-CO ₂ emissions [g CO ₂ e/MJ]
Biogas production and processing	65.3	0.540	42.9	0.350
Raw gas combustion, including flaring	29.6	114	-	-
Wood chip combustion	-	-	1.96	59.0
Biogas upgrading, polishing and liquefaction	-	-	3.22	0.365
LBG distribution	-	-	0.238	0
LBG combustion	-	-	0.227	2.86
LNG life cycle	113	0	-	-
Total²	208	114	48.5	62.6

The fossil carbon dioxide equivalent emissions for all sub processes in S1 amount to 208 g CO₂e/MJ and 48.5 g CO₂e/MJ in S2. The biogenic emissions add up to 114 g CO₂e/MJ in S1 and to 62.6 g CO₂e/MJ in S2. Given that the energy recovered in S2 surpasses that of S1, the result in Table 3 shows significantly lower emissions in S2. Providing an additional perspective, absolute emissions of carbon dioxide equivalents per year in each sub process and for the total of S1 and S2 are shown in Table 4.

²Due to rounding of data presented in the table, small differences in totals may occur.

Table 4*Emissions of Carbon Dioxide Equivalents by Process and in Total per Year in S1 and S2*

Process	Scenario 1		Scenario 2	
	Total emissions (excl. bio-CO ₂) [t CO ₂ e/yr]	Bio-CO ₂ emissions [t CO ₂ e/yr]	Total emissions (excl. bio-CO ₂) [t CO ₂ e/yr]	Bio-CO ₂ emissions [t CO ₂ e/yr]
Biogas production and processing	9 170	75.6	9 170	75.6
Raw gas combustion, including flaring	4 150	15 900	-	-
Wood chip combustion	-	-	420	12 600
Biogas upgrading, polishing and liquefaction	-	-	689	77.9
LBG distribution	-	-	50.8	0
LBG combustion	-	-	48.6	612
LNG life cycle	15 900	0	-	-
Total³	29 300	16 000	10 400	13 400

The fossil carbon dioxide equivalent emissions for all sub processes in S1 amount to 29 300 t CO₂e/yr and to 10 400 t CO₂e/yr in S2. The biogenic emissions add up to 16 000 t CO₂e/yr in S1 and to 13 400 t CO₂e/yr in S2. This means that S2 indicates lower emissions than S1 even in absolute terms.

4.2 Current Sustainability Reasoning within Domsjö Fabriker

The result of how key employees in a potential process change at Domsjö Fabriker reason about the company's sustainability efforts in general and in relation to the process change is presented in five themes. The themes are interpreted using the six concepts of ecocentric management, developed by Araujo et al. (2021), as a comparative reference. Each theme is presented with a description of what

³Due to rounding of data presented in the table, small differences in totals may occur.

has been interpreted within each individual theme, accompanied by quotes from the respondents illustrating their reasoning within the themes.

4.2.1 Financial Profit is the Major Priority

The theme *Financial Profit is the Major Priority* highlights how respondents reason about the importance of financial profit within Domsjö Fabriker. It is clear from all interviews that financial profit is considered the main incentive and focus regarding decision-making for process changes. Below is an excerpt where key informant A reasons about the main incentive for a potential change in the utilisation of Domsjö Fabriker's biogas.

The incentive is to get a new product... And a new source of income. That is the main thing. And it also strengthens our brand as a biorefinery. But the main thing is that we get a new product and a new source of income. (Key informant A)

An economic incentive is essential for the survival of a business. However, allowing economic profit to be the main priority can be problematic from an ecocentric perspective as it tends to neglect ecological factors and prioritise short-term gains over long-term sustainability. Within the concept of materiality, this kind of reasoning can therefore lead to undermining the recognition and consideration of ecological values in decision-making.

Some aspects, which are not emphasised as strongly in the interviews, show that Domsjö Fabriker strives for process solutions that are economically sustainable while being ecologically sustainable. In some cases, the organisation considers financial losses to be justified if they are environmental beneficial. One example is purchasing non-fossil fuelled vehicles, which according to key informant C entail an economic loss compared to fossil fuelled vehicles. Related to the concept of materiality, this can be interpreted as recognition of ecological responsibility. It also demonstrates an awareness of the need to integrate holistic sustainability aspects into business decisions by prioritising ecologically beneficial alternatives above economic gain.

4.2.2 Policy Instruments are Central in Sustainability Efforts

The theme *Policy Instruments are Central in Sustainability Efforts* aims to illustrate how respondents reason about the drivers behind sustainability efforts within Domsjö Fabriker. From all interviews it is shown that Domsjö Fabriker's sustainability initiatives are mainly motivated by policy instruments. Below is an example where key informant B explains from which incentives Domsjö Fabriker usually implements process changes.

A lot of environmental issues are governed by the requirements imposed by the authorities. So there may be things that cost a lot of money that do not result in improved quality or increased production and that would not have been invested in if there had not been environmental requirements. (Key informant B)

Within the concept of ecological sensemaking, it is central to acknowledge and address the values and needs of ecological factors. By solely prioritising compliance with generalised requirements in environmental efforts, Domsjö Fabriker may undermine the uniqueness of the place where they operate and neglect the broader and indirect ecological and social impacts of their actions. This is also reflected by the fact that the respondents repeatedly consider ecological sustainability to be equivalent to emission reductions. By undermining ecological values that are not directly affected by emissions, this reasoning suggests a deprioritisation of a holistic sustainability approach in decision-making.

4.2.3 Sustainability Consideration is Partially Managed Separately in the Organisation

The theme *Sustainability Consideration is Partially Managed Separately in the Organisation* highlights the delegation of responsibility for sustainability consideration at Domsjö Fabriker. Reasoning within this theme indicates that sustainability considerations are not fully integrated into the work of all employees, but are instead repeatedly referred to a separate department within the organisation. This is for example evident in the following excerpt from the interview with key informant A.

We do not have a main goal related to sustainability as a department, but we do work on some projects that are related to emission reductions. (Key informant A)

The division of responsibility suggests a lack of embeddedness, where it is not made clear to all employees how their individual work tasks can affect environmental and societal impact, therefore contributing to a disconnection between individual behaviours and ecological and social consequences. Delegating the responsibility for sustainability consideration to a single group of employees can also contribute to a lack of critical reflection and questioning of organisational activities at an individual level. Related to the concept of radical reflexivity, a critical culture is important to move away from ingrained assumptions and to foster holistic sustainable practices. As sustainability efforts are centralised to a specific department of Domsjö Fabriker, other parts of the

organisation may neglect their role and impact in promoting sustainability concerns, thus limiting the individual engagement and accountability in sustainable governance.

4.2.4 Sustainability Profiling and Responsible Role Modelling are Core Business Principles

The theme *Sustainability Profiling and Responsible Role Modelling are Core Business Principles* illustrates the expressed importance of emphasising the sustainability of the business model and processes of Domsjö Fabriker. Reasoning within this theme shows that the respondents consider business profiling as meaningful both from the perspective of acting as a sustainability role model in the context of other companies and countries, and from the perspective of branding and marketing. Below is an excerpt from the interview with key informant C, who discusses the responsibility of Domsjö Fabriker in promoting environmental accountability and sustainability within the Indian-owned company Aditya Birla.

We have a responsibility to support with our knowledge. We have made more progress on some [sustainability] issues in Sweden, as Westerners, but they are running very, very fast now, so we try to support them. (Key informant C)

Acting as pioneers in sustainable industry suggest that Domsjö Fabriker view themselves as a part of a global sustainable transition. Within the concept of embeddedness, this suggests that Domsjö Fabriker acknowledges their responsibility of, and interconnectedness with, broader environmental, societal, and spatial contexts. However, a recurring aspect in the interviews is the emphasis on the sustainability work of Domsjö Fabriker being important from a branding and marketing perspective. This raises a potential contradiction as it suggests that the organisation seeks financial benefits from sustainability initiatives. From an ecocentric perspective, this focus may pose challenges in maintaining a holistic stewardship by undermining the environmental and societal responsibilities, since it is then a matter of pursuing financial gain.

4.2.5 A Strong Sense of Responsibility towards the Direct Surrounding is Evident

The theme *A Strong Sense of Responsibility towards the Direct Surrounding is Evident* aims to highlight respondents' sense of responsibility towards the local community and the local environment. Reasoning within this theme shows that respondents mainly feel responsible towards social and ecological factors that are directly linked to the organisational activities of Domsjö Fabriker. The sense of social responsibility is for example evident in the following excerpt, where key informant C emphasises the importance of being a responsible employer.

Our goal is to maximise the tree's potential, but also to be a responsible employer. I believe we have a societal responsibility to demonstrate sustainability and how to work towards becoming a sustainable employer. (Key informant C)

This reasoning demonstrates a sense of responsibility towards the local community and highlights the relationship between Domsjö Fabriker and the prosperity of societal factors. Related to the concept of sense of place, this reflects an understanding of Domsjö Fabriker as an intrinsic part of its context, where the company's values are closely intertwined with the prosperity of the local community.

The respondents also express a sense of ecological responsibility. This is exemplified by their emphasis on responsibility towards the surrounding water recipient, where Domsjö Fabriker for example mitigates emissions and assesses fish stocks due to regulatory requirements by authorities. The recognition of the water recipient demonstrates a protective stance towards the ecological context. Related to the concept of uniqueness of place, this suggests that Domsjö Fabriker values the individuality of the location where they operate. The expressed sense of responsibility towards the water recipient is also influenced by regulatory requirements, making it difficult to determine whether the recognition of the water recipient is motivated by a sense of responsibility or legal requirements. However, throughout the interviews, respondents consistently indicate a clear sense of responsibility and concern regarding the surrounding environment.

4.3 Suggestions for Educational Measures

At Domsjö Fabriker, the economy and policy focused incentive to sustainability is distinct, while from an ecocentric perspective, the understanding that Domsjö Fabriker can benefit financially from long-term ecological stewardship is central (Araujo et al., 2021). Within the framework for transformative learning, one aim is to question prevailing assumptions and deepen the understanding of complex issues to enable conclusions based on comprehensive consideration, and to critically reflect on assumptions and their source, nature, and consequences (Mezirow, 2009). A suggestion for an educational measure for including an ecocentric mindset in decision-making, and in the organisation in general, is therefore to investigate and question whether ecological and economic sustainability are mutually exclusive in the processes at Domsjö Fabriker. This kind of radical reflexivity has the potential to allow the organisation to sustainably improve its operations in the context of its existing business model and strive for practices that are comprehensively sustainable and enable economic prosperity without the expense of ecological well-being.

At Domsjö Fabriker, reflection on sustainability is concentrated to a small group of employees. To increase the ecocentric embeddedness of the organisation and broaden the variation of understanding, the dependency to the social and ecological contexts of Domsjö Fabriker should be holistically addressed (Araujo et al., 2021). Within transformative learning, one approach to achieve comprehensive competence in the field of sustainability is to provide opportunities to constructively engage in multi-perspective discourses (Mezirow, 2009). One suggestion for an educational measure is therefore to involve every employee in sustainability reasoning, to ensure that everyone's thoughts, knowledge and concerns are taken into consideration, and offer opportunities for radical reflexivity for every employee. The approach for an educational measure should hence be to create an understanding of ecocentric management and offer opportunity for strategic reflection and reason on sustainability across different organisational aspects. This aims to ensure that every employee understands the relevance and potential related to their individual position in the organisation.

The perspective on environmental concern at Domsjö Fabriker appears to be limited to different types of emissions. Emissions constitute a significant part of the environmental impact of Domsjö Fabriker and are therefore relevant. Nevertheless, it is crucial to recognise the importance of several additional environmental and social aspects, as ecocentrism involves a holistic view of ecological and social well-being (Araujo et al., 2021). According to the transformative learning theory, education is preferably participatory and interactive (Mezirow, 1997). A suggestion for an educational measure to further enable multi-perspective discourse is therefore to strengthen the sensemaking and offer opportunities for discussion, for employees to recognise connections between different environmental and social aspects. Topics for such discussions can include frameworks such as the Planetary Boundaries and the SDGs, and can relate to, for example, the full circularity of produced products.

Another ecocentric aspect for a multi-perspective discourse is the ethics of materiality. At Domsjö Fabriker, natural ecosystems are considered stakeholders to some extent, but not on the basis that ecosystems have intrinsic value, which is essential within an ecocentric perspective (Araujo et al., 2021). According to the transformative learning framework, realisation and transformation originates from within and the educational content should preferably relate to personal experiences (Mezirow, 1997). A suggestion for an educational measure, to shift employees' perception from nature being an object to a stakeholder intertwined with society, is therefore to utilise the employees' local knowledge and sense of place, which may foster a deeper understanding of the interconnectedness between ecological factors and organisational activities. To further be

responsive to the sense of different places, and to acknowledge the responsibility in how products of Domsjö Fabriker affect other places than Örnsköldsvik throughout their life cycle, one suggestion is to provide employees with the opportunity to recognise and immerse in the uniqueness of all the locations impacted by the organisation, both directly and indirectly.

5 Discussion

The results are discussed in relation to previous research and theories, along with implications for future work. Furthermore, an evaluation of used methods, as well as a discussion of limitations, is carried out.

5.1 Discussion of Carbon Footprint Analysis

The results show that there is potential to reduce the carbon footprint of Domsjö Fabriker by liquefying and distributing internally produced biogas as vehicle gas. Depending on the choice of system boundaries, the results differ. The upgrading, liquefaction, and distribution process of LNG is not undertaken by Domsjö Fabriker, and it can therefore be relevant to review the carbon footprint of S1 without accounting for LNG life cycle. Excluding the LNG life cycle in S1 results in emissions of fossil carbon dioxide equivalents adding up to 94.9 g CO_{2e}/MJ. Expressed in terms of carbon dioxide equivalents per year yields 13 300 t CO_{2e}/yr in fossil emissions. Additionally, emissions from biogas production and processing can be excluded since they are included in both S1 and S2. Hence, if both the LNG life cycle and the biogas production and processing are excluded, the fossil emissions in S1 add up to 29.6 g CO_{2e}/MJ or 4 150 t CO_{2e}/yr. In S2, the fossil emissions correspond to 5.6 g CO_{2e}/MJ or 1 230 t CO_{2e}/yr. This consistent result, despite different system boundaries, confirms that there is a potential to reduce the carbon footprint by liquefying and distributing the biogas.

In the context of describing the result relative to the amount of recovered energy, it can be pertinent to examine the amount of external energy required for the production and distribution of bioenergy in the two scenarios. From a national energy distributional perspective, it can be perceived counterintuitive to expend a significant amount of energy to generate energy. Based on the calculation formulas outlined in Appendix A, the energy produced in S2 significantly surpasses that of S1, while the energy demand in S2 slightly surpasses that in S1. Hence, the increased energy consumption in S2 can be considered counterbalanced by the larger increase in energy production. However, it is important to acknowledge that utilisation of energy to produce energy can be advantageous in certain contexts, considering the varying demand and availability of different energy types and sources.

Definitive conclusions regarding the sustainability of bioenergy are not possible to make based on a carbon footprint analysis, since a transition to bioenergy to mitigate climate change may cause environmental trade-offs, creating a sustainability dilemma. For example, cultivation of energy crops may cause monoculture, disruption of biogeochemical flows, land system change, and overconsumption of freshwater (Bacovsky et al., 2022). Implementing circular waste-to-energy principles through cascaded use of biomass enables to benefit from locked-in energy while mitigating negative ecological impact. Harnessing the energy of biomass residues at Domsjö Fabriker is a way of valorising waste and rendering it useful. The substantially higher amount of energy recovered in S2 shows that the scenario has the potential to be more efficient from that perspective. However, whether the life cycle is fully circular is questionable. To achieve circularity in a cradle-to-cradle life cycle perspective for biogas production, the material source and the end-of-life state should, according to Elia et al. (2017), remain largely preserved. Biomaterial that is harvested from tree plantations may not fully adhere to circular principles as the cradle is altered by human intervention. Furthermore, the circularity relies on conservation and replantation of natural forest, to the same extent as it is being harvested, to preserve carbon sinks and to preserve the functioning of ecosystems (Bacovsky et al., 2022; Hyvönen et al., 2023).

It is assumed in the scenario description that LBG produced by Domsjö Fabriker substitutes LNG, resulting in a positive reduction of fossil carbon dioxide equivalent emissions in S2. However, if the substituted vehicle gas is to originate from sources with a smaller carbon footprint than LNG, the result could be misleading. Furthermore, it is possible that the carbon footprint of LBG produced from alternative cascaded biomaterials may be smaller than that of LBG produced from volatile biomass residues at Domsjö Fabriker. Assuming the demand or distribution possibilities of LBG is limited, there might be a risk associated with substituting LBG from Domsjö Fabriker with a smaller carbon footprint alternative. In such a scenario, it might be relevant to consider the carbon footprint benefit of producing LBG at Domsjö Fabriker in contrast to vehicle gas derived from alternative feedstocks.

Comparing the findings of this study with prior research to validate the results may be challenging due to unique factors such as system boundaries, selected methods, assumptions, and production contexts significantly influencing the outcome. In a study conducted by Uusitalo et al. (2014) in a Finnish context, the carbon footprint of different feedstocks and scenarios for biogas utilisation are examined. The findings show that upgrading biogas to CBG results in lower greenhouse gas emissions compared to other scenarios, such as using biogas to operate a gas turbine or gas engine. The study compares the production and distribution of CBG via gas grids, which is different from the

end product and distribution method chosen in this study, making direct comparisons impossible. However, the result from Uusitalo et al. can provide insights and serve as complementary indicators for Domsjö Fabriker. Similar results as shown by Uusitalo et al. are also evident in a study conducted by Bakkaloglu and Hawkes (2024), where greenhouse gas emissions of upgrading biogas for transportational use and utilising biogas for combined heat and power generation are estimated.

5.1.1 Other Possible Technical Solutions and Assumptions

The assumption of producing LBG in S2 was primarily made due to reasons concerning distribution and an increased national demand. However, producing CBG from biomass residues and distributing it in tanks is possible, making CBG an alternative product for Domsjö Fabriker (Klackenberg, 2024). Nonetheless, studies show that upgrading and distributing LBG rather than CBG potentially contribute to a smaller carbon footprint (Gustafsson et al., 2020; Tekniska verken, 2017). Furthermore, the assumption of utilising the produced LBG for road transportation in heavy duty vehicles was made. Upgraded biogas can also be used in the maritime sector, where it has great potential to contribute to fossil-free shipping (Klackenberg, 2024). The advantage of distributing biogas to both road and maritime transportation is that biogas is a fossil-free alternative for heavy transports where, for example, electrification is not as beneficial (Bacovsky et al., 2022). A further aspect regarding utilisation of the LBG is whether it can be used locally. Utilising products locally implicates shortened or eliminated transportation distances and thus reduced emissions linked to distribution. From a social sustainability perspective, it can be beneficial to find uses for products as locally as possible to avoid depleting resources in a place where the local population does not benefit from the extraction or production (de la Cadena, 2015).

A significant proportion of the emissions in both S1 and S2 are generated in the initial production of biogas. Data of emission factors from biogas production are general and do not consider the exact process of Domsjö Fabriker, hence the estimated emissions may differ from actual emissions. However, the obtained data show that the majority of these emissions arise from the disposal of digestate without containment, as well as from open sedimentation basins (Swedish Energy Agency, 2021b). Thus, this way of managing the digestate constitutes a significant factor for improvement at Domsjö Fabriker regardless of a potential upgrading and distribution of the biogas.

An assumed addition in the upgrading process is catalytic oxidation. Not including catalytic oxidation implies higher emissions of methane, which has 25 times larger GWP than carbon dioxide, therefore resulting in a larger carbon footprint (Swedish Standards Institute [SIS], 2013). In the calculation of emissions, the oxidised methane is included as a biogenic carbon dioxide emission. As Domsjö

Fabriker, at the time of this study, collects and distributes carbon dioxide from other processes, it may be an option to examine the potential in utilising the carbon dioxide produced in the catalytic oxidation as well. Furthermore, the carbon dioxide that is removed in the membrane separation and polishing is not added to the calculations of emissions, due to the possibility of recovering and distributing the carbon dioxide as an additional product (Gustafsson et al., 2020). If the carbon dioxide is not to be collected by Domsjö Fabriker, it should be considered as a biogenic emission.

5.1.2 Economic Implications from Scenarios of Biogas Utilisation

One aim of a biorefinery is to benefit as much as possible from the natural circularity of carbon through a bioeconomic system. Consequently, the production of LBG demonstrates significant potential in this regard. In Sweden, the import of LBG is rapidly increasing which implies a demand (Klackenberg, 2024). There is hence a market for LBG, especially in road and maritime transport. Furthermore, the Swedish Energy Agency, commissioned by the government, is tasked with disbursing a climate premium for vehicles, including trucks intended to be powered by biogas (Swedish Energy Agency, 2023b). This could potentially further secure demand. In addition, from a global political perspective, the assurance of reliable energy production can be considered nationally beneficial (Swedish Energy Agency, 2022c). One aspect to consider, however, is whether future market saturation levels will affect long-term demand dynamics, and hence the economic potential available to Domsjö Fabriker. In this context, it is relevant to analyse market prices and availability in relation to production prices for different kinds of feedstocks to assess whether LBG produced at Domsjö Fabriker are likely to be established and stable on the market.

Until 2023, according to a decision of the European Commission, Sweden had a tax exemption on biogas (Swedish Energy Agency, 2020). However, in March 2023, the General Court of the European Union annulled the decision (Swedish Tax Agency, 2023). This has, according to Klackenberg (2024) at Swedish Gas Association, caused a high pressure on both production and demand of biomethane. Concurrently with regulations concerning tax exemptions, Sweden has a government-funded production subsidy for biogas upgraded to biomethane in gas or liquid form (SFS 2022:225). The production subsidy for upgrading can be provided to operators engaged in the production of biogas subsequently upgraded, and the production subsidy for liquefaction can be offered to operators producing biogas subsequently liquefied. In addition, a governmental investment support programme called the Climate Leap initiative can be applied for operators in need of economic support for installing for example upgrading and liquefaction units (Swedish Environmental Protection Agency, 2024b, 2024c). Similar projects as upgrading biogas to LBG at Domsjö Fabriker have received funding through the initiative (Tekniska verken, n.d.).

The decision regarding production of CBG or LBG from an economic perspective largely depends on where the product will be distributed. Upgraded biogas intended to be utilised locally might imply that liquefaction is not economically beneficial. In a study by Gustafsson et al. (2020), the cost of producing LBG was calculated to exceed the cost of producing CBG, but the cost of transporting LBG was lower than the cost of transporting CBG. The break-even point for CBG and LBG is, according to the study, a transportation distance of 25-250 km, depending on upgrading methods. Similar results are found in a pre-study at Tekniska verken (2017), whereas the break-even point is at approximately 120 km. Thus, if Domsjö Fabriker can sell the vehicle gas to a local consumer, CBG may be a better option from an economic perspective.

5.1.3 Uncertainties of Carbon Footprint Calculations

An uncertainty analysis of this study has not been applied due to the characteristics of the calculations and data sets. The calculations relied upon established data of emission factors, flows and energy consumption etcetera. These data were assumed to be valid throughout the analysis due to their authoritative sources. However, without access to detailed information regarding the uncertainties inherent in these datasets, it was not feasible to conduct a robust uncertainty assessment. Nevertheless, there are some known uncertainties in the collected datasets. One evident uncertainty is that the system boundaries in the calculations of the data are in some cases unknown and in some cases inconsistent. One example of inconsistency is that the emission factor of electricity usage in Sweden supposedly includes emissions from construction, whilst the emission factors of combustion supposedly only include direct emissions (Swedish Environmental Protection Agency, 2023). Another uncertainty regarding system boundaries of calculated data is whether operational energy is included in emission factors. For instance, it is uncertain if operational energy is accounted for in the emission factors for combustion. Where such uncertainties have occurred, the worst-case scenario has been applied, and thus emissions from operational energy have been added to emission factors. Consequently, the resultant emission estimates should be interpreted within the context of these uncertainties, acknowledging the potential for inherent inaccuracies within the data inputs.

In some cases, collected data lacks precision regarding description which also limits the certainty of calculations. This is evident in the example of the biogas production, where there are uncertainties of the inclusion of biogenic carbon in emission factors. Another example is the emission factor for electricity consumption, where the proportion of biogenic and fossil carbon is not specified. This vagueness could imply that biogenic carbon has been excluded from the emission factor or that a portion of the emission factor should be considered as biogenic. In this study, the entire emission

factor for electricity consumption has been calculated as fossil. No assumptions about additional biogenic emissions have been included as this would be arbitrary. Moreover, the emission factors from biogas production are disaggregated and described in g CO₂e/MJ per process step. However, at the end of all processes, there should be less energy remaining than at the end of the first process, which, in this case, makes unclear whether MJ in the emission factor refers to the energy at that particular process step or the energy at the end of all processes. To apply the worst-case scenario, the initial energy flow is accounted for as it results in higher emissions. Nevertheless, the significance is relatively small.

Another factor contributing to uncertainty is that several data points are approximate. For instance, all combustion emission factors are based on averages calculated from data provided by various Swedish industries (Swedish Environmental Protection Agency, 2023). Furthermore, data obtained from Domsjö Fabriker are also approximate. For example, the operating energy for the flare in S1 is assumed to be negligible, and the composition of the raw gas is estimated. Moreover, estimates have been made in calculations. Examples of this is that temperatures have been estimated in calculations concerning gas volumes and that efficiency rates have not been accounted for, unless otherwise specified. An assumption that may overlook some energy consumption is that any energy input required for storing LBG at the filling station and at Domsjö Fabriker has not been considered, as no information suggesting such a need has been found. Furthermore, the assumption is made that all LBG produced will be utilised, even though LBG may evaporate if it is left for too long. Excluded emissions can thus occur from re-liquefaction or boil-off methane if it cannot be used as CBG (Gustafsson et al., 2020).

5.2 Discussion of Development of Educational Measures

The result indicates that key informants at Domsjö Fabriker partly reason within the concepts of ecocentric management. However, some reasoning also suggests areas for further improvement to enable the organisation to align more comprehensively with ecocentric ideals. A possible explanation to the dual reasoning may be the conflict of interest between the organisation's sustainability vision and the market-driven society in which it operates. Domsjö Fabriker is hence required to navigate between market demands and principles for ecological governance, which may shift their focus towards short-term gains rather than long-term ecological sustainability (Winter-Simat et al., 2017). The result therefore emphasises the relevance to integrate ecocentric principles in organisational activities and decision-making, to foster holistic and long-term sustainability within Domsjö Fabriker, and thus strengthen its ecocentric management. The result also indicates that policy instruments serve as core guidelines for sustainability efforts at Domsjö Fabriker, which

implies the importance of well-defined and comprehensive national and international policy instruments.

The suggested educational measures in this study intend to enhance sustainable decision-making within Domsjö Fabriker. Furthermore, the measures can be applied in a more general context as they mainly are designed to foster a culture of reflection and critical thinking among employees. This approach aims to strengthen the ecocentric culture over time by enabling employees to autonomously devise methods for enhancing the sustainability of their tasks, without being given prescriptive guidance. To achieve this development in approach, it is essential that Domsjö Fabriker advocates this culture at core, thus creating opportunities for each employee to reflect on suggested issues in their everyday work. By doing so, the ecocentric approach can become embedded in the organisation's values, fostering a mindset where ecological responsibility is integrated into decision-making and organisational activities. The suggested measures thus provide a foundation for further work by Domsjö Fabriker, requiring the company to design suitable activities based on these suggestions to ensure their relevance and meaningfulness. For these measures to be applicable, a long-term commitment and profound dedication on the part of Domsjö Fabriker are therefore needed. Furthermore, by utilising local knowledge, in accordance with ecocentric principles, within the global company Aditya Birla, Domsjö Fabriker may have the potential to contribute to enhanced sustainability in global business practices.

5.2.1 Evaluation of Methodology for Development of Educational Measures

Although the intention was to select key informants from different positions within Domsjö Fabriker to highlight different perspectives, the quantity and composition of the studied group may not fully capture the diversity of perspectives and reasoning within the organisation. The selection of participants was based on involvement in the potential process change. At the time of this study, a limited number of employees within Domsjö Fabriker had insight into the potential change in biogas utilisation. This limitation may therefore have impacted the diversity of the perspectives gathered in this study, potentially limiting the validity of the results.

By asking open questions in the interviews, the intention was to obtain answers that genuinely reflect the informants' reasoning. Nonetheless, informants may have been inclined to provide answers that were perceived as more favourable or aligned with organisational and societal expectations. However, the responses in the interviews show that the informants have not responded in a way that would imply this.

5.3 Further Studies

Further studies have been briefly suggested in the previous discussion to illuminate uncertainties and ensure reliability. However, there are additional aspects, in addition to sources of uncertainties, which are relevant to analyse in future studies.

The carbon footprint analysis was delimited to exclude emissions from deforestation. However, deforestation potentially has an impact on the carbon footprint due to the loss of carbon sinks (Hyvönen et al., 2023). In further studies, the potential increase in deforestation, due to for example increased profit incentive, should be assessed. Furthermore, the possibility of the potential process change to contribute to biodiversity loss or natural land transformation and other impact categories should be analysed, to obtain a holistic understanding of potential ecological impacts. Moreover, it is relevant to consider the full life cycle in such studies. Another delimitation that has been made in the calculations of the carbon footprint in this study is emissions of greenhouse gases from construction of upgrading and distributional facilities. Some emission factors include emissions from constructions, but no calculations concerning constructions of industrial facilities at Domsjö Fabriker have been included. In further studies, carbon footprints for constructions and maintenance of such facilities should be calculated.

The development of suggestions for educational measures is conducted under the assumption that ecocentric management fosters sustainability, and that the cultivation of an ecocentric reasoning can be facilitated through transformative learning. However, it would be of interest to examine the efficiency of the suggested educational measures in fostering an ecocentric mindset and, consequently, promoting sustainability, through transformative learning. Moreover, it is relevant to include and analyse additional factors that may influence employees' sustainability reasoning. For instance, trade unions and business customers could be deemed relevant stakeholders in such a context. Furthermore, given that Domsjö Fabriker is owned by Aditya Birla, it is pertinent to investigate how reasoning and decision-making regarding sustainability are influenced by them.

5.4 Conclusions

The carbon footprint associated with internal utilisation of self-produced biogas at Domsjö Fabriker is calculated to 208 g CO₂e/MJ or 29 300 t CO₂e/yr, excluding biogenic carbon dioxide emissions. Furthermore, the carbon footprint associated with upgrading, distribution, and utilisation of the biogas as vehicle gas adds up to 48.5 g CO₂e/MJ or 16 000 t CO₂e/yr, excluding biogenic carbon dioxide emissions. Hence, the results show that there is potential to reduce the carbon footprint by

producing LBG, both in terms of carbon dioxide equivalent emissions relative to recovered energy and in terms of absolute carbon dioxide equivalent emissions per year and in each scenario. Furthermore, the analysis of the biogas utilisation scenarios shows that there is potential to recover significantly more of the energy in biogas produced at Domsjö Fabriker by upgrading and liquefying it to LBG. Moreover, economic implications and demand indicate a positive potential. However, sources of uncertainties, as well as alternative assumptions, might have a significant impact on the results, and based on the discussion, it is eminent that the single-issue delimitation of the analysis may hide ecological trade-off effects.

It is understood that Domsjö Fabriker strives to be a sustainability pioneer. The overall business model of the company is based on circular material flows and bioeconomy, which enables the company to continue its operations without depleting its resources. The organisation also employs this edge to act as exemplars and disseminate knowledge about sustainable methodologies. On the other hand, Domsjö Fabriker has a strong economic incentive that sometimes seems to dominate. As a result, the company tends to limit itself to complying with existing policy instruments and standard requirements. Educational measures that can be implemented to enhance sustainability in decision-making are preferably participatory, interactive, and relate to personal experiences, intending to foster critical reflection and enable a multi-perspective discourse among all employees, hence fostering an ecocentric culture within Domsjö Fabriker over time. Furthermore, educational measures should aim to enable acknowledgement of different environmental and social aspects and include various perceptions. Educational measures should also aim to offer knowledge on how organisational practices can enable economic prosperity without the expense of ecological sustainability. The discussion of this study shows that the suggested educational measures are applicable to strengthen sustainability in the organisation in general, enhancing the ecocentric management at core.

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Appendix A Formulas for Carbon Footprint Calculations

Quantities and quantity symbols used in calculations are shown in Table A1 followed by formulas of calculations of flows and carbon equivalent emissions.

Table A1

List of quantities, quantity symbols and units used in calculations

Quantity	Quantity symbol	Unit
Emission factor electricity utilisation Sweden	EF_e	kg CO ₂ e/Wh
Emission factor LNG life cycle	EF_{LNG}	kg CO ₂ e/J
Emission factor biogas production and processing	EF_{BGP}	kg CO ₂ e/J
Emission factor raw gas stationary combustion	EF_{RGC,CO_2}	kg CO ₂ /J
	EF_{RGC,CH_4}	kg CH ₄ /J
	EF_{RGC,N_2O}	kg N ₂ O/J
Emission factor wood chip combustion	EF_{WCC,CO_2}	kg CO ₂ /J
	EF_{WCC,CH_4}	kg CH ₄ /J
	EF_{WCC,N_2O}	kg N ₂ O/J
Emission factor diesel MK1 combustion	EF_{DC}	kg CO ₂ e/J
Emission factor LBG heavy duty vehicle combustion	EF_{LBGC,CO_2}	kg CO ₂ /J
	EF_{LBGC,CH_4}	kg CH ₄ /J
Global warming potential	GWP_{CO_2}	
	GWP_{CH_4}	
	GWP_{N_2O}	
Electricity demand lignin dryers	$E_{D,LD}$	Wh/yr
Electricity demand wood chip boiler	$E_{D,WCB}$	Wh/yr
Electricity demand biogas upgrading	$E_{D,MS}$	Wh/Nm ³ raw gas
Electricity demand catalytic oxidation	$E_{D,CO}$	Wh/Nm ³ raw gas
Electricity demand biogas polishing	$E_{D,P}$	Wh/kg LBG
Electricity demand biogas liquefaction		Wh/Nm ³ polished biogas
	$E_{D,TBL}$	
Electricity demand LBG fuelling	$E_{D,Fu}$	Wh/Nm ³ LBG
Diesel MK1 demand truck	$D_{D,T}$	L/m
Energy content diesel MK1	$E_{C,D}$	J/L
Total transportation distance, distribution LBG	$d_{T,LBG}$	m/yr
Amount of biogas (raw gas) produced	$E_{Pr,BG}$	J/yr or Wh/yr
	$V_{Pr,BG}$	Nm ³ /yr
Amount of biogas upgraded	$E_{U,BG}$	J/yr or Wh/yr
Amount of biogas polished	$E_{Po,BG}$	Wh/yr
	$V_{Po,BG}$	Nm ³ /yr

Amount of biogas liquefied	$E_{L,BG}$ $V_{L,BG}$ $m_{L,BG}$	J/yr Nm ³ /yr kg/yr
Amount of energy utilised in lignin dryers	$E_{U,LD}$	J/yr or Wh/yr
Amount of energy flared	E_F	J/yr or Wh/yr
Energy content methane	$E_{C,CH4}$	Wh/Nm ³ or Wh/kg
Energy content upgraded biogas	$E_{C,BG}$	Wh/Nm ³
Energy content polished biogas	$E_{C,PBG}$	Wh/ Nm ³
Energy content LBG	$E_{C,LBG}$	J/kg or J/Nm ³
Density carbon dioxide	ρ_{CO2}	kg/m ³
Molar mass methane	M_{CH4}	g/mole
Molar mass carbon dioxide	M_{CO2}	g/mole
Proportion of methane in raw gas	Pr_{CH4}	%
Proportion of biogenic emissions for biogas (raw gas) production and processing	$Pr_{BE,P}$	%
Proportion of energy utilised in lignin dryers	Pr_{ELD}	%
Proportion of energy flared	Pr_{EF}	%
Methane slippage biogas upgrading	$Pr_{CH4,MS}$	%
Methane slippage catalytic oxidation	$Pr_{CH4,CO}$	%
Methane slippage biogas polishing	$Pr_{CH4,P}$	%
Methane slippage biogas liquefaction	$Pr_{CH4,TBL}$	%
Emissions within process	Em	kg CO ₂ e/yr
Fossil emissions within process	Em_F	kg CO ₂ e/yr
Biogenic emissions within process	Em_B	kg CO ₂ e/yr
Total fossil emissions from process described in absolute emissions and in functional unit	$TE_{F,AE}$ $TE_{F,FU}$	kg CO ₂ e/yr kg CO ₂ e/MJ
Total biogenic emissions from process described in absolute emissions and in functional unit	$TE_{B,AE}$ $TE_{B,FU}$	kg CO ₂ e/yr kg CO ₂ e/MJ

Formulas for Calculations of flows

Volume of biogas (raw gas) production is given by

$$\frac{E_{Pr,BG}}{E_{C,CH4} \cdot Pr_{CH4}} = V_{Pr,BG}$$

$$\left[\frac{\text{MWh/yr}}{\text{MWh/Nm}^3} = \text{Nm}^3/\text{yr} \right]$$

Amount of energy utilised for lignin dryers is given by

$$E_{Pr,BG} \cdot Pr_{ELD} = E_{U,LD}$$

$$[\text{GWh/yr} = \text{GWh/yr}]$$

Amount of energy flared is given by

$$E_{Pr,BG} \cdot Pr_{EF} = E_F$$

$$[\text{GWh/yr} = \text{GWh/yr}]$$

Amount of energy obtained after the upgrading process is given by

$$E_{Pr,BG} \cdot (1 - Pr_{CH4,MS}) = E_{U,BG}$$

$$[\text{GWh/yr} = \text{GWh/yr}]$$

Amount of energy obtained after the polishing process is given by

$$E_{U,BG} \cdot (1 - Pr_{CH4,P}) = E_{Po,BG}$$

$$[\text{GWh/yr} = \text{GWh/yr}]$$

$$\frac{E_{Po,BG}}{E_{C,PBG}} = V_{Po,BG}$$

$$\left[\frac{\text{kWh/yr}}{\text{kWh/Nm}^3} = \text{Nm}^3/\text{yr} \right]$$

Amount of energy obtained after the liquefaction process is given by

$$E_{Po,BG} \cdot (1 - Pr_{CH4,TBL}) = E_{L,BG}$$

$$[\text{GWh/yr} = \text{GWh/yr}]$$

$$\frac{E_{L,BG}}{E_{C,LBG}} = m_{L,BG}$$

$$\left[\frac{\text{MJ/yr}}{\text{MJ/kg}} = \text{kg/yr} \right]$$

$$\frac{E_{L,BG}}{E_{C,LBG}} = V_{L,BG}$$

$$\left[\frac{\text{MJ/yr}}{\text{MJ/Nm}^3} = \text{Nm}^3/\text{yr} \right]$$

Formulas for Calculations of Emissions from Biogas Production and Processing

Amount of emitted carbon dioxide equivalents from biogas production and processing is given by

$$EF_{BGP} \cdot E_{Pr,BG} = Em$$

$$[\text{kg CO}_2\text{e/MJ}] \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/yr}$$

Whereas emissions accounted for as fossil is given by

$$Em \cdot (1 - Pr_{BE,P}) = Em_F$$

$$[\text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from biogas production and processing is given by

$$Em_F = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from biogas production and processing in scenario 1 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{U,LD}} = TE_{F,FU,S1}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted fossil carbon dioxide equivalents from biogas production and processing in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU,S2}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from biogas production and processing is given by

$$Em - TE_{F,AE} = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e/yr} - \text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted biogenic carbon dioxide equivalents from biogas production and processing in scenario 1 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{U,LD}} = TE_{B,FU,S1}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from biogas production and processing in scenario 2 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{L,BG}} = TE_{B,FU,S2}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from Raw Gas Combustion

Amount of emitted carbon dioxide equivalents from raw gas combustion for lignin dryers is given by

$$EF_{RGC,CO_2} \cdot GWP_{CO_2} \cdot E_{U,LD} + EF_{RGC,CH_4} \cdot GWP_{CH_4} \cdot E_{U,LD} + EF_{RGC,N_2O} \cdot GWP_{N_2O} \cdot E_{U,LD} = Em_1$$

$$[\text{kg CO}_2/\text{MJ}] \cdot \text{MJ/yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ/yr} + \text{kg N}_2\text{O}/\text{MJ} \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/yr}]$$

Whereas emissions accounted for as fossil is given by

$$EF_{RGC,CH_4} \cdot GWP_{CH_4} \cdot E_{U,LD} + EF_{RGC,N_2O} \cdot GWP_{N_2O} \cdot E_{U,LD} = Em_{F,1}$$

$$[\text{kg CO}_2/\text{MJ}] \cdot \text{MJ/yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/yr}]$$

Amount of emitted carbon dioxide equivalents from energy consumption for lignin dryers, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,LD} = Em_{F,2}$$

$$[\text{kg CO}_2/\text{kWh} \cdot \text{kWh/yr} = \text{kg CO}_2/\text{yr}]$$

Amount of emitted carbon dioxide equivalents from flaring is given by

$$EF_{RGC,CO_2} \cdot GWP_{CO_2} \cdot E_F + EF_{RGC,CH_4} \cdot GWP_{CH_4} \cdot E_F + EF_{RGC,N_2O} \cdot GWP_{N_2O} \cdot E_F = Em_2$$

$$[\text{kg CO}_2/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg N}_2\text{O}/\text{MJ} \cdot \text{MJ}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Whereas emissions accounted for as fossil is given by

$$EF_{RGC,CH_4} \cdot GWP_{CH_4} \cdot E_F + EF_{RGC,N_2O} \cdot GWP_{N_2O} \cdot E_F = Em_{F,3}$$

$$[\text{kg CO}_2/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from raw gas combustion in lignin dryers and flaring is given by

$$Em_{F,1} + Em_{F,2} + Em_{F,3} = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e}/\text{yr} + \text{kg CO}_2\text{e}/\text{yr} + \text{kg CO}_2\text{e}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from raw gas combustion in scenario 1 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{U,LD}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e}/\text{yr}}{\text{MJ}/\text{yr}} = \text{kg CO}_2\text{e}/\text{MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from raw gas combustion in lignin dryers and flaring is given by

$$Em_1 + Em_2 - TE_{F,AE} = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e}/\text{yr} + \text{kg CO}_2\text{e}/\text{yr} - \text{kg CO}_2\text{e}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted biogenic carbon dioxide equivalents from raw gas combustion in scenario 1 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{U,LD}} = TE_{B,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e}/\text{yr}}{\text{MJ}/\text{yr}} = \text{kg CO}_2\text{e}/\text{MJ} \right]$$

Formulas for Calculations of Emissions from Wood Chip Combustion

Amount of emitted carbon dioxide equivalents from wood chip combustion for lignin dryers is given by

$$EF_{WCC,CO_2} \cdot GWP_{CO_2} \cdot E_{U,LD} + EF_{WCC,CH_4} \cdot GWP_{CH_4} \cdot E_{U,LD} + EF_{WCC,N_2O} \cdot GWP_{N_2O} \cdot E_{U,LD} = Em$$

$$[\text{kg CO}_2/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg N}_2\text{O}/\text{MJ} \cdot \text{MJ}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Whereas emissions accounted for as fossil is given by

$$EF_{WCC,CH_4} \cdot GWP_{CH_4} \cdot E_{U,LD} + EF_{WCC,N_2O} \cdot GWP_{N_2O} \cdot E_{U,LD} = Em_{F,1}$$

$$[\text{kg CH}_4/\text{MJ} \cdot \text{MJ}/\text{yr} + \text{kg N}_2\text{O}/\text{MJ} \cdot \text{MJ}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Amount of emitted carbon dioxide equivalents from energy consumption for wood chip boilers, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,WCB} = Em_{F,2}$$

$$[\text{kg CO}_2\text{e}/\text{kWh} \cdot \text{kWh}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from wood chip combustion in lignin dryers is given by

$$Em_{F,1} + Em_{F,2} = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e}/\text{yr} + \text{kg CO}_2\text{e}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from wood chip combustion in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e}/\text{yr}}{\text{MJ}/\text{yr}} = \text{kg CO}_2\text{e}/\text{MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from wood chip combustion in lignin dryers and flaring is given by

$$Em - TE_F = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e}/\text{yr} - \text{kg CO}_2\text{e}/\text{yr} = \text{kg CO}_2\text{e}/\text{yr}]$$

Total amount of emitted biogenic carbon dioxide equivalents from wood chip combustion in scenario 2 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{L,BG}} = TE_{B,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from Upgrading

Amount of emitted carbon dioxide equivalents from energy consumption for membrane separation, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,MS} \cdot V_{Pr,BG} = Em_{F,1}$$

$$[\text{kg CO}_2\text{e/kWh} \cdot \text{kWh/Nm}^3 \cdot \text{Nm}^3/\text{yr} = \text{kg CO}_2\text{e/yr}]$$

Amount of emitted carbon dioxide equivalents from energy consumption for catalytic oxidation, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,CO} \cdot V_{Pr,BG} = Em_{F,2}$$

$$[\text{kg CO}_2/\text{kWh} \cdot \text{kWh/Nm}^3 \cdot \text{Nm}^3/\text{yr} = \text{kg CO}_2/\text{yr}]$$

Amount of emitted methane from slippage in catalytic oxidation, whereas everything is accounted for as fossil, is given by

$$\frac{E_{Pr,BG} \cdot Pr_{CH_4,MS} \cdot Pr_{CH_4,CO} \cdot GWP_{CH_4}}{E_{C,CH_4}} = Em_{F,3}$$

$$\left[\frac{\text{kWh/yr}}{\text{kWh/kg}} = \text{kg CO}_2\text{e/yr} \right]$$

Amount of emitted carbon dioxide from oxidised methane in catalytic oxidation, whereas everything is accounted for as biogenic, is given by

$$\frac{E_{Pr,BG} \cdot Pr_{CH_4,MS} \cdot (1 - Pr_{CH_4,CO}) \cdot M_{CO_2} \cdot GWP_{CO_2}}{E_{C,CH_4} \cdot M_{CH_4}} = Em_{B,1}$$

$$\left[\frac{\text{kWh/yr} \cdot \text{g/mole}}{\text{kWh/kg} \cdot \text{g/mole}} = \text{kg CO}_2\text{e/yr} \right]$$

Amount of slipped carbon dioxide from catalytic oxidation, whereas everything is accounted for as biogenic, is given by

$$\left(\frac{E_{Pr,BG} \cdot Pr_{CH4,MS}}{E_{C,CH4} \cdot Pr_{CH4}} - \frac{E_{Pr,BG} \cdot Pr_{CH4,MS}}{E_{C,CH4}} \right) \cdot \rho_{CO2} \cdot GWP_{CO2} = Em_{B,2}$$

$$\left[\left(\frac{\text{kWh/yr}}{\text{kWh/Nm}^3} - \frac{\text{kWh/yr}}{\text{kWh/Nm}^3} \right) \cdot \text{kg/m}^3 = \text{kg CO}_2\text{e/yr} \right]$$

Total amount of emitted fossil carbon dioxide equivalents from upgrading is given by

$$Em_{F,1} + Em_{F,2} + Em_{F,3} = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/yr} + \text{kg CO}_2\text{e/yr} + \text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from upgrading in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from upgrading is given by

$$Em_{B,1} + Em_{B,2} = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e/yr} + \text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted biogenic carbon dioxide equivalents from upgrading in scenario 2 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{L,BG}} = TE_{B,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from Polishing

Amount of emitted carbon dioxide equivalents from energy consumption for polishing, whereas all

emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,P} \cdot m_{L,BG} = Em_F$$

$$[\text{kg CO}_2\text{e/kWh} \cdot \text{kWh/kg} \cdot \text{kg/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from polishing is given by

$$Em_F = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from polishing in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from Liquefaction

Amount of emitted carbon dioxide equivalents from energy consumption for Turbo-Bryton Liquefaction, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,TBL} \cdot V_{Po,BG} = Em_{F,1}$$

$$[\text{kg CO}_2\text{e/kWh} \cdot \text{kWh/Nm}^3 \cdot \text{Nm}^3/\text{yr} = \text{kg CO}_2\text{e/yr}]$$

Amount of emitted carbon dioxide equivalents from methane slippage in Turbo-Bryton liquefaction, whereas everything is accounted for as fossil, is given by

$$GWP_{CH_4} \left(\frac{E_{Po,BG} \cdot (1 - Pr_{CH_4,TBL})}{E_{C,CH_4}} \right) = Em_{F,2}$$

$$\left[\frac{\text{kWh/yr}}{\text{kWh/kg}} = \text{kg CO}_2\text{e/yr} \right]$$

Amount of emitted carbon dioxide equivalents from carbon dioxide slippage in Turbo-Bryton liquefaction, whereas everything is accounted for as biogenic, is given by

$$GWP_{CO_2} \cdot \rho_{CO_2} \left(\frac{E_{Po,BG} \cdot (1 - Pr_{CH_4,TBL})}{E_{C,BG}} - \frac{E_{Po,BG} \cdot (1 - Pr_{CH_4,TBL})}{E_{C,CH_4}} \right) = Em_B$$

$$\left[\text{kg/m}^3 \cdot \left(\frac{\text{kWh/yr}}{\text{kWh/Nm}^3} - \frac{\text{kWh/yr}}{\text{kWh/Nm}^3} \right) = \text{kg CO}_2\text{e/yr} \right]$$

Total amount of emitted fossil carbon dioxide equivalents from Turbo-Bryton liquefaction is given by

$$Em_{F,1} + Em_{F,2} = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/yr} + \text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from Turbo-Bryton liquefaction in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from Turbo-Bryton liquefaction is given by

$$Em_B = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted biogenic carbon dioxide equivalents from Turbo-Bryton liquefaction in scenario 2 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{L,BG}} = TE_{B,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from Distribution

Amount of emitted carbon dioxide equivalents from transportation of LBG in diesel MK1 trucks, whereas all emissions are accounted for as fossil, is given by

$$EF_{DC} \cdot d_{T,LBG} \cdot D_{D,T} \cdot E_{C,D} = Em_{F,1}$$

$$[\text{kg CO}_2\text{e/MJ}] \cdot \text{km/yr} \cdot \text{L/km} \cdot \text{MJ/L} = \text{kg CO}_2\text{e/yr}]$$

Amount of emitted carbon dioxide equivalents from energy consumption for fuelling, whereas all emissions are accounted for as fossil, is given by

$$EF_e \cdot E_{D,Fu} \cdot V_{L,BG} = Em_{F,2}$$

$$[\text{kg CO}_2\text{e/kWh} \cdot \text{kWh/Nm}_3 \cdot \text{Nm}_3/\text{yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from raw gas combustion in lignin dryers and flaring is given by

$$Em_{F,1} + Em_{F,2} = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/yr} + \text{kg CO}_2\text{e/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from distribution in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from LBG Combustion

Amount of emitted carbon dioxide equivalents from LBG combustion in heavy duty vehicles is given by

$$EF_{LBGC,CO_2} \cdot GWP_{CO_2} \cdot E_{L,BG} + EF_{LBGC,CH_4} \cdot GWP_{CH_4} \cdot E_{L,BG} = Em$$

$$[\text{kg CO}_2/\text{MJ}] \cdot \text{MJ/yr} + \text{kg CH}_4/\text{MJ} \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/MJ}]$$

Whereas emissions accounted for as fossil is given by

$$EF_{LBGC,CH_4} \cdot GWP_{CH_4} \cdot E_{L,BG} = Em_F$$

$$[\text{kg CH}_4/\text{MJ}] \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/MJ}]$$

Total amount of emitted fossil carbon dioxide equivalents from LBG combustion in heavy duty vehicles is given by

$$Em_F = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/MJ}] = \text{kg CO}_2\text{e/MJ}]$$

Total amount of emitted fossil carbon dioxide equivalents from LBG combustion in scenario 2 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{L,BG}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Total amount of emitted biogenic carbon dioxide equivalents from LBG combustion in heavy duty vehicles is given by

$$Em - TE_{F,AE} = TE_{B,AE}$$

$$[\text{kg CO}_2\text{e/MJ}] - \text{kg CO}_2\text{e/MJ}] = \text{kg CO}_2\text{e/MJ}]$$

Total amount of emitted biogenic carbon dioxide equivalents from LBG combustion in scenario 2 described in the functional unit is given by

$$\frac{TE_{B,AE}}{E_{L,BG}} = TE_{B,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Formulas for Calculations of Emissions from LNG Life Cycle

Amount of emitted carbon dioxide equivalents LNG lifecycle, whereas all emissions are accounted for as fossil, is given by

$$EF_{LNG} \cdot E_{L,BG} = Em_F$$

$$[\text{kg CO}_2\text{e/MJ}] \cdot \text{MJ/yr} = \text{kg CO}_2\text{e/yr}]$$

Total amount of emitted fossil carbon dioxide equivalents from LNG life cycle is given by

$$Em_F = TE_{F,AE}$$

$$[\text{kg CO}_2\text{e/MJ}] = \text{kg CO}_2\text{e/MJ}]$$

Total amount of emitted fossil carbon dioxide equivalents from LNG life cycle in scenario 1 described in the functional unit is given by

$$\frac{TE_{F,AE}}{E_{U,LD}} = TE_{F,FU}$$

$$\left[\frac{\text{kg CO}_2\text{e/yr}}{\text{MJ/yr}} = \text{kg CO}_2\text{e/MJ} \right]$$

Appendix B Assumptions for Carbon Footprint Calculations

General Assumptions

The raw gas is assumed to be composed of 75 vol.% CH₄ and 25 vol.% CO₂. The energy content for methane is set to 9.97 kWh/Nm³ and 13.9 kWh/kg. For electricity use, the emission factor for Sweden's electricity mix was used, i.e. 26 g CO₂e/kWh, whereas all emissions are accounted for as fossil.

Biogas Production and Processing

For the emission factor related to biogas production and processing, it is assumed that the digestate is non-contained, corresponding to an emission factor of 42.8 g CO₂e/MJ. Furthermore, the emission factor for contained digestate corresponds to 7.2 g CO₂e/MJ. Therefore, it is assumed that pure raw gas slippage from this step amount to 42.8 - 7.2 = 35.6 g CO₂e/MJ. Additional assumptions based on the Global Warming Potential (GWP) of methane and carbon dioxide, and the composition of the raw gas, results in 0.818% of the emitted carbon dioxide equivalents from biogas production being estimated to be biogenic.

Raw Gas Combustion

It is assumed that 65% of the produced biogas is used to operate the lignin dryers and that the remaining 35% of the biogas is flared. Used emission factors for these combustions are 93.0 g CO₂/MJ, 0.001 g CH₄/MJ, and 0.0001 g N₂O/MJ, which are based on general data for biogas combustion. Furthermore, the lignin dryers are assumed to have an electrical power of 20 kW, operating for 345 d/yr and 24 h/d. External energy input required to operate the flare is assumed to be negligible. Any gas slippage in the combustion of biogas is assumed to be included in the emission factors.

Wood Chip Combustion

Since 65% of the produced biogas is utilised in the lignin dryers, it is assumed that 65% of the total energy production is required to operate the lignin dryers, i.e. 140 400 GJ/yr. Therefore, it is assumed that wood chip combustion corresponding to 140 400 GJ/yr is required. Furthermore, it is assumed that the amount of wood chips needed to operate the lignin dryers is available at Domsjö Fabriker, i.e. no external supply.

When calculating emissions from wood chip combustion, the moisture content of the wood chips is assumed to be 50% and a calorimetric value is used. Hence, used emission factors for wood chip combustion are 89.87 kg CO₂/GJ, 0.011 kg CH₄/GJ, and 0.005 kg N₂O/GJ. Furthermore, it is assumed that the proposed wood chip boiler operates for 345 d/yr and 24 h/d, and that required operating energy is 10% of its power, i.e. 0.8 MW.

Biogas Upgrading

Biogas upgrading is assumed to be performed using membrane separation technology with three modules. Hence, the electricity demand used for calculations is 0.25 kWh/Nm³ raw gas and the methane slippage is 0.5% of the inlet stream of raw gas. The energy content of the upgraded biogas is set to 9.7 kWh/Nm³. Furthermore, the molar mass of methane is assumed to be 16.04 g/mol and the molar mass of carbon dioxide is assumed to be 44.01 g/mol.

It is assumed that catalytic oxidation converts 95% of the methane in the off-gas, with the remaining emissions in the off-gas calculated based on the composition of the raw gas. For calculations of emissions in the catalytic oxidation, the temperature of the gases is assumed to be 0 °C. Therefore, the density for carbon dioxide is set to 1.98 g/dm³. Furthermore, it is assumed that the electricity demand for the catalytic oxidation (0.05 kWh/Nm³ raw biogas) depends on the total amount of raw gas entering the upgrading process and not the amount of off-gas. Hence, calculations of emissions derived from energy input in the catalytic oxidation are based on 8 020 000 Nm³ raw gas. Lastly, carbon dioxide emissions in the catalytic oxidation are not assumed to be collected by Domsjö Fabriker.

Biogas Polishing

It is assumed that the electricity demand for polishing (0.15 kWh/kg LBG) depends on the total amount of LBG produced and not the amount of gas undergoing polishing. Hence, calculations of emissions derived from energy input in biogas polishing are based on 4 300 000 kg LBG.

Furthermore, the methane slippage in the polishing step is assumed to be negligible, meaning there is no energy loss. After biogas upgrading and polishing, the gas is assumed to have a purity of 99.995%. The energy content of the polished biogas is hence set to 9,97 kWh/Nm³.

Biogas Liquefaction

For liquefaction of biogas, it is assumed that Turbo-Brayton refrigeration is used. Hence, the electricity demand used for calculations is 0.29 kWh/Nm³ biogas and the methane slippage is 0.5% of

the inlet stream of gas. For calculations of emissions in biogas liquefaction, the temperature of the gases is assumed to be 0 °C. Therefore, the density for carbon dioxide is set to 1.98 g/dm³. Furthermore, it is assumed that the energy content for LBG is 9.9 kWh/Nm³ and 50 MJ/kg.

LBG Distribution

It is assumed that each truck used for transporting LBG between Domsjö Fabriker and the fuelling station is transported 500 km, including empty transports. Furthermore, it is assumed that the transportation of LBG is carried out using diesel trucks, where each truck transports 30 tonnes of LBG and consumes 0.3 L diesel/km. Since the amount of produced LBG is 4 300 000 kg, the number of trucks required for transportation of LBG is 142.46 per year. The total amount of transportation kilometres per year is hence 71 230 km/yr. Moreover, the energy content for diesel is assumed to be 35.5 MJ/L and the emission factor used for diesel combustion is 66.7 g CO_{2e}/MJ.

It is assumed that the LBG tank of the transportation truck is fully emptied at the fuelling station and that no additional compression of the LBG is required at the fuelling station. Lastly, it is assumed that the electricity demand for fuelling with LBG is 0.0032 kWh/Nm³ LBG.

LBG Combustion

The produced LBG is assumed to be used in road transportation with heavy duty vehicles. Furthermore, it is assumed that the emission factor for combustion remains consistent between LNG and LBG, with the adjustment that combustion of LBG generates biogenic carbon dioxide emissions. The emission factors for LBG combustion used for calculations are hence 2.86 g CH₄/MJ and 0.00909 g CO₂/MJ.

LNG Life Cycle

The emissions generated in the LNG life cycle are assumed to correspond to an emission factor of 74.5 g CO_{2e}/MJ. Furthermore, it is assumed that the amount of LBG produced by Domsjö Fabriker (213 TJ/yr) will substitute the same amount of LNG on the market.

Appendix C Interview Guide

The interview guide used in the interviews is presented below. The interview was held in Swedish, hence the interview guide is written in Swedish.

Övergripande hållbarhetsarbete

Kan du beskriva hur du uppfattar Domsjös övergripande synsätt kring hållbarhet?

Har du några huvudmål i ditt hållbarhetsarbete? Vilka i så fall?

Hur mäter och utvärderar Domsjö framstegen och resultaten av hållbarhetsinitiativ?

Vilka indikatorer använder Domsjö för att bedöma er prestation på detta område?

Hur ser du på Domsjös ansvar i att främja hållbart samhälle och miljö?

Hur ser du på Domsjös ansvar för sina produkter ur ett livscykelperspektiv, exempelvis hur bioråvara är framställd samt vad som händer med Domsjös produkter efter att de lämnat fabriken?

(Globalt och lokalt; textilfabriker / skogsbruk / monokultur / ohållbar kläindustri / kemikalier / cirkularitet).

Hur ser du på Domsjös roll som aktör i att främja miljöansvar och hållbarhet inom Aditya Birla?

Vidtar Domsjö några åtgärder för att påverka "uppåt" i organisationen?

Incitament för processförändringar

Vilket anser du är det huvudsakliga incitamentet med en eventuell förändring i användningen av Domsjös biogas?

Utifrån vilket/vilka incitament är din uppfattning att Domsjö brukar genomföra processförändringar?

Det kan uppstå konflikter mellan ekonomiska mål och miljö- eller samhällsmässiga mål. Hur ser du att Domsjö hanterar sådana konflikter?

Vilka strategier ser du att Domsjö använder för att balansera dessa olika intressen?

Genomförande av processförändringar

På vilket sätt anser du att processförändringen för den producerade biogasen kan stärka Domsjös hållbarhetsarbete?

På vilket sätt ser du att Domsjö integrerar hållbarhetsprinciper i beslutsfattande om processförändringar? Vilka hållbarhetsprinciper ingår?

Ser du att ekosystem som direkt eller indirekt påverkas av Domsjös verksamhet är en intressent/aktör? (På vilket sätt tar du det i beaktning vid processförändringar?)

(På vilket sätt ser du att Domsjö tar omgivande miljö och lokalsamhälle i beaktning vid beslutsfattande av processförändringar? Exempel?)

(På vilket sätt ser du att Domsjö säkerställer att beslut kring processförändringar görs med beaktning av samtliga direkta och indirekta aktörer/intressenter (inklusive ekosystem)?)

Med avseende på vilka aspekter är din uppfattning att Domsjö utvärderar utfall av processförändringar? (Alltså efter att en processförändring genomförts.)

Utbildning och reflektion

Vilka rutiner har Domsjö för att främja kontinuerlig reflektion och kritisk analys kring hållbarhet av befintliga rutiner, processer och antaganden?

Vilket eller vilka perspektiv ser du kan främja den kontinuerliga reflektionen och analysen för att leda till en förbättrad verksamhet?

Har du något exempel på hur en sådan reflexiv process lett till förändringar eller förbättringar?

Kan du identifiera områden där ytterligare utbildning och kunskapsutveckling skulle kunna gynna Domsjös hållbarhetsarbete i samband med processförändringar?

Något mer du vill tillägga som vi inte kommit in på?

Appendix D Interview Information Sheet

The E-mail sent to respondents prior the interviews is presented below. The interview was held in Swedish, hence the E-mail is written in Swedish.

Hej,

Här kommer lite information och frågor inför intervjun.

Intervjun ämnar kartlägga hur ni resonerar kring hållbarhet i allmänhet och i relation till processförändringar. Utifrån era svar ska vi sedan ge förslag på utbildningsinsatser för att komplettera Domsjös hållbarhetsprofil vid beslutsfattande. Nedan bifogas ett utkast på de frågor vi kommer att beröra under intervjun. Frågorna utgör vår planerade intervjuguide och är därmed något vi kan komma att frånga. Vi förväntar oss inte att ni förbereder er, utan bifogar dem för er skull ifall ni vill veta vilken typ av frågor vi kommer ställa.

För att säkerställa att vi uppfattar det ni säger så korrekt som möjligt önskar vi spela in intervjun. Inspelningen kommer sedan transkriberas och därefter raderas. Transkriberingen kommer därefter översättas till engelska och skickas till dig, om du vill, för granskning och godkännande. Efter avslutat examensarbete kommer även transkriberingen att raderas. All data kommer att förvaras säkert och endast vara tillgänglig för oss (Ellen och IdaMaria).

Vi är inte ute efter någon säkerhetskänslig information och du väljer helt och hållet själv vad du svarar på och inte. Informationen kommer endast användas till vårt examensarbete.

Ditt namn, kön och ålder kommer inte att inkluderas i rapporten. Däremot kommer du att benämnas som "nyckelperson" eller liknande och Domsjö Fabriker kommer att benämnas.

Känns detta okej?

Är det okej att vi spelar in intervjun?

Vill du ha transkriberingen skickad till dig efter intervjun?

Vänlig hälsning

Ellen och IdaMaria

Här kommer frågorna:

Kan du beskriva hur du uppfattar Domsjös övergripande synsätt kring hållbarhet?

Har du några huvudmål i ditt hållbarhetsarbete? Vilka i så fall?

Hur mäter och utvärderar Domsjö framstegen och resultaten av era hållbarhetsinitiativ?

Vilka indikatorer använder Domsjö för att bedöma er prestation på detta område?

Hur ser du på Domsjös ansvar i att främja hållbart samhälle och miljö?

Hur ser du på Domsjös ansvar för sina produkter ur ett livscykelperspektiv, exempelvis hur bioråvara är framställd samt vad som händer med Domsjös produkter efter att de lämnat fabriken?

Hur ser du på Domsjös roll som aktör i att främja miljöansvar och hållbarhet inom Aditya Birla?

Vidtar Domsjö några åtgärder för att påverka "uppåt" i organisationen?

Vilket anser du är det huvudsakliga incitamentet med en eventuell förändring i användningen av Domsjös biogas?

Utifrån vilket/vilka incitament är din uppfattning att Domsjö brukar genomföra processförändringar?

Det kan uppstå konflikter mellan ekonomiska mål och miljö- eller samhällsmässiga mål. Hur ser du att Domsjö hanterar sådana konflikter?

Vilka strategier ser du att Domsjö använder för att balansera dessa olika intressen?

På vilket sätt anser du att processförändringen för den producerade biogasen kan stärka Domsjös hållbarhetsarbete?

På vilket sätt ser du att Domsjö integrerar hållbarhetsprinciper i beslutsfattande om processförändringar? Vilka hållbarhetsprinciper ingår?

Ser du att ekosystem som direkt eller indirekt påverkas av Domsjös verksamhet är en intressent/aktör? (På vilket sätt tar du det i beaktning vid processförändringar?)

(På vilket sätt ser du att Domsjö tar omgivande miljö och lokalsamhälle i beaktning vid beslutsfattande av processförändringar? Exempel?)

(På vilket sätt ser du att Domsjö säkerställer att beslut kring processförändringar görs med beaktning av samtliga direkta och indirekta aktörer/intressenter (inklusive ekosystem)?)

Med avseende på vilka aspekter är din uppfattning att Domsjö utvärderar utfall av processförändringar? (Alltså efter att en processförändring genomförts.)

Vilka rutiner har Domsjö för att främja kontinuerlig reflektion och kritisk analys kring hållbarhet av befintliga rutiner, processer och antaganden?

Vilket eller vilka perspektiv ser du kan främja den kontinuerliga reflektionen och analysen för att leda till en förbättrad verksamhet?

Har du något exempel på hur en sådan reflexiv process lett till förändringar eller förbättringar?

Kan du identifiera områden där ytterligare utbildning och kunskapsutveckling skulle kunna gynna Domsjös hållbarhetsarbete i samband med processförändringar?

