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Liquefied Natural Gas Regasification Terminals: Life Cycle Assessment/Carbon Footprint Tool and Proposal for Decarbonization Solutions

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As the world contemplates a more sustainable future, energy systems and value chains' decarbonization has been thrown into the spotlight. Liquefied Natural Gas (LNG) is considered the cleanest fossil fuel, but Greenhouse Gas (GHG) emissions are produced during its value chain. For an advanced engineering platform in the oil and gas sector that plays a leading role in the new global low-carbon energy and industrial ecosystem, there is a need to strengthen this role by developing a methodology, a database, and an explicit tool that guides their approach when tendering or designing and building LNG regasification terminal projects. This tool will be developed based on regulations and standards related to GHG emissions, which are the Kyoto Protocol and ISO 14067 standards, respectively. Therefore, the objective of this work is to carry out a lifecycle analysis in order to estimate the carbon footprint of a typical LNG regasification terminal, based on which a list of decarbonization solutions would be proposed and analyzed considering the major's emissive items, to determine their effect on the terminal's Capital Expenses (CAPEX) and Operating Expenses (OPEX).

1. Introduction

According to the International Energy Agency (IEA), replacing coal with gas at power plants could help reduce CO_2 emissions by 5 Gt/y, where, for example, switching just 20 % of coal-fired power in Asia to gas can potentially save up to 680 Mt/y (MTPA) of CO_2 emissions (equivalent to all emissions in Germany), and switching 10 % of heavy goods vehicles and 10 % of shipping fleet to run on gas can potentially save up to 75 MTPA of CO_2 (equivalent to 16.3 million cars being taken off-road). This strengthens the position of natural gas in the energy sector and would likely increase the global demand for LNG in the market because of its relatively lower cost and lower contribution of emissions from production and combustion. The use of green gas is also clearly increasing, and for producers located geographically far from natural gas grid infrastructure, the most profitable way of transportation for the biomethane is as liquefied biomethane (Oudghiri et al., 2018). Comer et al. (2022) predict that by 2030 global LNG demand will increase to 36.2 Mt, about three times higher than in 2019. Assuming the European Union (EU) will maintain its 2019 share of global demand (20.5 %), it is anticipated that ships travelling to, from, and between EU ports will require 7.42 Mt of LNG in 2030. Roman-White et al. (2021) highlighted the importance of customized life-cycle assessments in improving GHG emission estimations and differentiating supply chains to provide business and policy decisions related to the transition to a low-carbon future.

Despite LNG's reputation as the cleanest burning fossil fuel, its GHG emissions during its value chain are under increased scrutiny (Bordage, 2019). The present work aims to assess an explicit methodology for the life cycle/carbon footprint estimation of a typical regasification terminal. Furthermore, the study will identify the major emissive sources and propose applicable decarbonization solutions considering Capital Expenses (CAPEX) and Operating Expenses (OPEX). The regasification terminal in this study is a receiving/import facility located in Europe with a capacity of 12 Billion Cubic Meter (BCM) nominal per year (equivalent to 8.7 MTPA LNG),

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which entails two LNG tanks with a net-working capacity of 240,000 m^3 and all associated regasification facilities and infrastructure. This study has been highlighted for the sake of the project's environmental perspective.

2. Estimation method

To perform the LCA, a carbon footprint estimation tool should be developed following the American Petroleum Institute (API) and ISO 14060 standards methodology for oil and natural gas. The GHGs concerned are CO_2 emissions. Typically, a Life Cycle Analysis (LCA) includes the manufacturing and transportation of each equipment and component that will be used to construct and operate the terminal, the construction which includes all activities and operations that will take place before the commissioning and start-up phases, the operation and maintenance phases and decommissioning which are activities involved at the end of life of the terminal. However, our scope work will focus on manufacturing (scope 3), transportation (scope 3), and operation (scope 2) phases because of project boundaries and the battery limit of the Engineering Procurement and Construction (EPC) contract. The estimation method used is based on Eq.(2):

$$\text{Emission} = Activity\ \ factor * Emissions\ factor \tag{2}$$

- ✓ Activity data is a measure of human activity that generates GHG emissions. Activity data include tons of fuel used, kWh of energy purchased, miles driven, etc.
- ✓ Emission factors are pollutant-specific coefficients that quantify their emissions per unit of activity data.
- ✓ Emission represents the carbon footprint estimated value in tonnes CO_2-eq

Figure 1 gives an overview of the entire terminal system, showing the battery limit of the project. Our scope of work would be inside this defined battery limit.

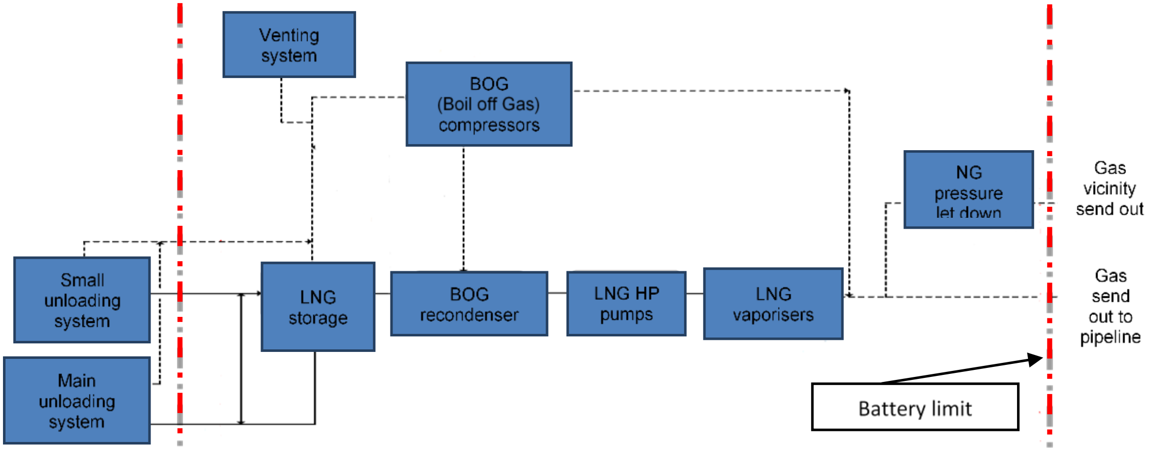

Figure 1: Boundary system and functional unit

2.1 Assessments and hotspots emissions

The LCA includes the equipment and component with important volume or quantity. So, referring to the previous formula, the main outcomes obtained for the CO_2 emissions estimation are presented for each phase of the life cycle. These are the points that need our attention for the different phases. Tables 1, 2, and 3 show each phase's items with important emissions which will require our attention for the investigation step.

The previous step has presented the major emissive sources, and a list of mitigation solutions has been proposed to reduce them. However, they need more investigation considering the effects of CAPEX and OPEX. To be more aware of mitigation measures and demonstrate the feasibility of their implementation, more details should be clarified and studied according to the specificity of the terminal. Thus, the effects of some of these decarbonization solutions on CAPEX-OPEX and return on investment were evaluated. Then, a preliminary list of solutions with their associated effects on CAPEX and OPEX in percentage or unit rate form was established, thus creating an internal reference of decarbonization solutions that will be ready to be proposed to clients in upcoming bids and projects of LNG regasification terminals.

Table 1: Hotspots emissions

Phases	Manufacturing (scope 3 upstream)	Transportation (scope 3 upstream)	Operation (scope 1&2)
LNG storage tank	Concrete Reinforcing steel	Insulation Reinforced steel	Low cap. LP pump High cap. LP pump
Equipment	ORV (Open Rack Vaporizer) BOG compressor LNG HP pumps	BOG compressor ORV LNG HP pumps	HP pump Low cap HP pump LP BOG compressor LP/HP hybrid BOG compressor Let down water heater Let down electrical

Table 2: Mitigations solutions

Manufacturing (scope 3 upstream)	Transportation (scope 3 upstream)	Operation (scope 1&2)
Consider for each material, if possible, supplier that has more sustainable (CCS plan). Optimize the storage tanks design (dimensions, thickness, weight) Evaluate location for storage tanks with better geotechnical conditions, to reduce the piles configuration.	The alternatives either for sea or road transportation can considering the nearest supplier who will deliver over the shortest distance Apply for sustainable fuels Prioritizing sea or river transport whenever applicable	Refer to the table of BAT (Table 3)

Table 3: Mitigations solutions for operations (BAT) (Dorosz et al., 2018)

Best Available Technology for Energy Efficiency (BAT)	BAT description
Boil-off and loading arm gas recovery	Boil-off gas and gas inventory included in the loading arm shall be recovered (e.g., recirculated back to the process or used as fuel).
Light Emitting Diode (LED) Lights	Use of LED lights at indoor and outdoor when possible.
Variable-speed drives - Variable Frequency Drives (VFD)	The control of electrical VFD is accomplished by converting the fixed frequency of incoming alternating current (AC) voltage to direct current (DC) — and then reconverting it back to AC voltage by varying the frequency with solid state electronics. Typically, application are electric motors on centrifugal pumps, centrifugal compressor, air coolers, etc...
Flare/Vent Recovery Unit (VRU)	Deployment of a system to capture and reuse LP discharges to the flare or the application of closed flare system.
Combined-Cycle Gas Turbine (CCGT)	Consider a CCGT plant (Gas turbine + steam turbine combined cycle) for main power generation.
Full Electric	Consider a full-electric approach (all machines driven by electric motor) to have a single CO_2 emission point.
Renewables	Evaluate integration with renewable energy (solar PV) even at small scale, in consideration of layout constraints at offshore, as long as reasonably feasible (e.g., small-scale PV for civil uses).

3. Decarbonization solution

Different ways were studied for lowering CO_2 emissions at the major point of our typical terminal lifecycle. They intend to identify the adequate method and system to perform the terminal at appropriate costs and in sustainable way. In the estimation method part, some mitigation solutions were presented. The following section will consist of choosing and applied adequate and affordable mitigation techniques for each phase, considering the technology level maturity and the state of ongoing R & D.

3.1 Manufacturing and transportation

The major sources of emissions are concrete, steel, vaporizers and compressors. These sources represent more than 82.43 % of the overall manufacturing emission phase. For clarity, concrete and steel here include the quantity of the following components: storage tanks, buildings, pipe racks, foundations, etc. The source of these emissions at this phase is mainly produced by the fabrication of raw materials. Selection of raw materials with low carbon emissions can have a significant impact on the manufacturing of a certain product. Hence, considering some assumptions, two scenarios were carried out. Scenario 1 is a set of conventional items, and scenario 2 is based on low-carbon items (low-carbon concrete and recycled steel). Scenario 2 allows for a reduction of 60 % of the emissions of Scenario 1. There is no issue with having the nearest supplier; the better way to lower emissions is by considering a sustainable fuel. Two scenarios of vessel fuel consumption were considered: MGO and LNG. The LNG fuel scenario helps us to reduce approximately 20 % of the MGO fuel scenario.

3.2 Operations

3.2.1 Electricity consumption

All the equipment is needed for the terminal operation. Among them, the most electricity consumer are pumps and BOG compressors (over 70 % for this study case). The mode which requires attention is the one when NG sends out simultaneously loading and unloading mode, and the main issue is BOG management. The maximum permitted value for BOG seems to differ from case to case. In fact, there is no consensus regarding standard values, knowing, logically, that the lower the daily BOG, the less energy losses will be with this mode. However, for our case study, the daily BOG rate has been estimated at 0.05 %. BOG remains a key issue for economic and technical reasons, as its rate also influences the safety (pressure increase inside the tank) and total cost of the terminal. The operation phase is the major source of energy consumption and, therefore, CO_2 emissions. The main issue to address to lower them is proposing a good BOG management, which is a scope of work granted to process team.

3.2.2 LNG Vessel rotation

Good management of ship trips for LNG delivery can significantly influence CO_2 emissions. Figure 2 and Figure 3 will consider two scenarios for two export countries to evaluate the vessel rotation emission for the lifetime of the terminal (25 y). The terminal capacity is 8.7 MTPA = 21.5 million m^3 of LNG. The fuels considered are MGO (Marine Gasoil) and LNG.

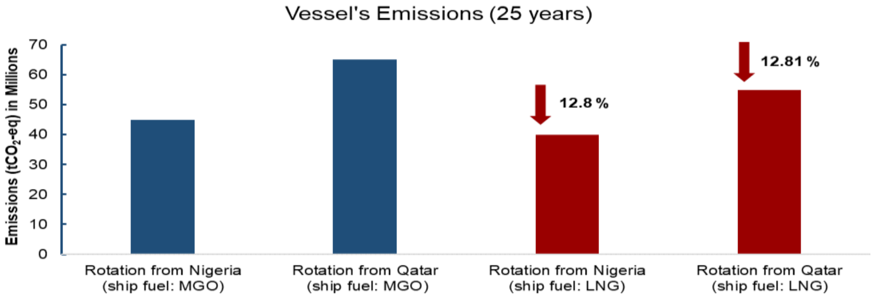

Figure 2: Different Vessel's rotation emission (25 years)

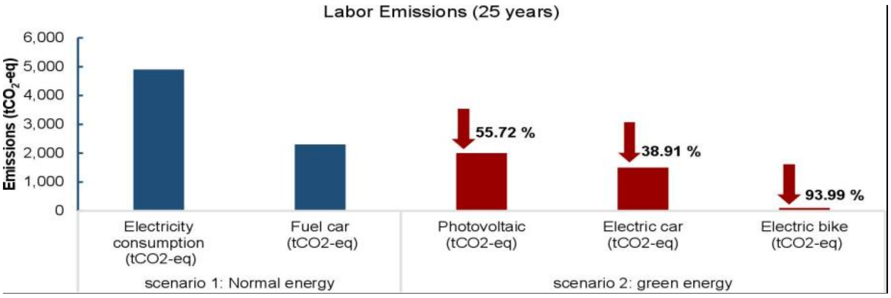

Figure 3: Two scenarios for emissions per labor

3.2.3 Labor impact

Calculating an employee’s carbon footprint can also be essential to know the impact of that work on our environment in terms of greenhouse gas emissions. However, calculating the carbon footprint of an LNG terminal employee can be complicated because of the variety of parameters to be considered. In our case, the two most emissive points are considered: electricity and fuel consumption on site. For each of them, different scenarios are proposed.

Table 4: CAPEX estimation for manufacturing (p: piece)

			Scenario 1			Scenario 2	
Equipment		Unit	Price (€/unit)	Total Prices (€)	∆ price (€/unit	Price (€/unit)	Total Prices (€)
	Concrete	m^3	187	16,233,544	10.7 %	207.01	17,970,534
	Steel	t	830	7,512,711	12.6 %	453.58	3,732,328
BOG Compressor	ORV	6 p	3,370,000	20,220,000	4.94 %	3,504,800	21,028,800
	Desuperheater	1 p	161,000	161,000		161,000	161,000
	LP/HP & LP Hybrid BOG compressor	6 p	2,910,000	2,910,000	2,910,000	2,910,000	2,910,000
	Compressor drum	1 p	160,000	160,000		160,000	160,000
Venting	drum heater & KO drum	2 p	269,542	269,542		269,542	269,542
Recondenser	BOG recondenser	1 p	523,700	523,700		523,700	523,700
Let pressure down	Electrical & water heater	2 p	1,425,304	1,425,304	1,425,304	1,425,304	1,425,304
LNG Pump	HP pump	7 p	1,200,000	8,400,000		1,200,000	8,400,000
	low-capacity & blending pump	7 p	1,200,000	8,400,000		1,200,000	8,400,000
Tank	Low cap LP Pumps	8 p	1,100,000	8,800,000		1,100,000	8,800,000
	High cap LP pumps	4 p	1,100,000	4,400,000		1,100,000	4,400,000
Total (€)				83,080,529			83,228,908

Table 5: CAPEX estimation for transportation

Items	Quantities (pieces)	Units	Weight	Freight Tons	Costs (€)
LP/HP Hybrid BOG compressor	2	t	365	1460	553,340
LP BOG Compressors	1	t	250	1000	173,500
BOG Compressor drum	1	t	10.3	41.2	6,715.6
Liquid Accumulator	1	t	2.85	11.4	1,550.4
ORV (Open Rack Vaporizer)	6	t	78	514.8	535,906.8
Foam glass	/	m^3	489.55		36,200
Expanded Perlite	/	m^3	12,900		418,500
Bituminous Felt	/	m^3	159.91		12,400
Resilient Blanket	/	m^3	67.27		6,200
Total					1,745,312.8

4. Capital Expenses and Operating Expenses Investigation

4.1 CAPEX Breakdown

Usually, this exercise evaluates the capital expenditure of the overall EPC project. However, in our scope of work, only the CAPEX of some items will be addressed. The objective is to compare the initial CAPEX (scenario 1) with a new CAPEX (scenario 2). Scenario 2 considers items with low carbon impact. The two points of our CAPEX study will be based on the manufacturing (Table 4) and transportation (Table 5) phases.

4.2 OPEX breakdown

The terminal's operating cost will consider the majors following points: vessel ship rotation costs, electricity consumption costs (Table 6) on the terminal, and labor costs.

Table 6: Electricity Costs

Components	Power (kWh)	Unit prices (€/kWh)	Total prices (€)
Low-Capacity LP Pump LNG TANK	462	0.15	554.4
High-Capacity LP Pump LNG TANK	316	0.15	189.6
Vicinity let down electrical heater	3,500	0.15	525
LP/HP Hybrid BOG compressor	2,115	0.15	634.5
LP BOG Compressors	2,115	0.15	634.5
High Pressure pump	2,015	0.15	1,813.5
low-capacity HP pump	969	0.15	145.35
blending pump	205	0.15	30.75
Total	11,697		4,527.6

5. Conclusion

The LCA/Carbon footprint assessment was performed based on an estimation approach that revealed the following outcomes for the 3 scopes: Scope 1: 0.19 %, Scope 2: 99.79 %, and Scope 3: 0.013 %. Based on various assumptions detailed in this study, two investigations have been carried out. For the manufacturing phase, a mature solution has been investigated to produce items through recycled material. It is less emissive, and the items keep the same properties. Using items manufactured by recycling raw materials can reduce 50 % of emissions for the entire manufacturing phase. For the transportation phase, two types of fuels (LNG & MGO) for vessels have been explored. As most of the equipment would be delivered from the USA and east ASIA, it can be clearly concluded that the LNG solution is the more suitable one. It came out to a reduction of around 19.85 % in CO_2 emissions. For the operation phase, the major source of energy consumption and CO2 emissions, the main issue to address is proposing a balanced BOG management, which is a scope of work under the process design team. Also, two scenarios are proposed for LNG delivery by ship, thus noticing a reduction of 12.8 % if Nigeria is taken as the exporting country instead of Qatar. Concerning the electricity consumption by the working resources within an operating terminal (administrative, operational labor, etc.), photovoltaic energy can decrease consumption by approximately 55.72 % compared to the national grid. The results showed that the CAPEX would marginally increase by around 0.17 % if complete low-carbon emission items were considered for the project. Concerning the OPEX outcomes, based on the assumptions adopted during the operation stage, particularly the power consumption, a decrease of 0.015 % has been noticed if low-carbon emissions items were considered. For higher accuracy, the results of OPEX would need more development at a further stage.

References

Bordage F., 2019, The environmental footprint of the digital world, GreenIT.fr, <https://www.greenit.fr/wp-content/uploads/2019/11/GREENIT_EENM_etude_EN_accessible.pdf>, accessed 04.04.2023.

Comer B., O'Malley J., Osipova L., Pavlenko N., 2022, Comparing the future demand for, supply of, and life-cycle emissions from bio, synthetic, and fossil LNG marine fuels in the European Union, International Council on Clean Transportation (ICCT), Washington, DC, US.

Dorosz P., Wojcieszak P., Malecha Z., 2018, Exergetic Analysis, Optimization and Comparison of LNG Cold Exergy Recovery Systems for Transportation. Entropy, 20(1), 59.

Oudghiri I., Tinoco R.R., Bouallou C., 2018, Exergy analysis, optimization approach and transient mode operation study of non-flammable biomethane liquefaction process. Chemical Engineering Transactions, 70, 1537-1542.

Roman-White S.A., Littlefield J.A., Fleury K.G., Allen D.T., Balcombe P., Konschnik K.E., Ewing J., Ross G.B., George F., 2021, LNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting. ACS Sustainable Chemistry & Engineering, 9, 10857−10867.