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Achieving Carbon Neutrality for A Future Large Greenhouse Gas Emitter in Quebec, Canada: A Case Study

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Abstract: To reach the Paris Agreement targets of holding the global temperature increase below 2 °C above the preindustrial levels, every human activity will need to be carbon neutral by 2050. Feasible means for industries to achieve carbon neutrality must be developed and assessed economically. Herein we present a case study on available solutions to achieve net-zero carbon from the get-go for a planned liquefied natural gas (LNG) plant in Quebec, which would classify as a large Canadian greenhouse gas (GHG) emitter. From a literature review, available options were prioritized with the promoter. Each prioritized potential solution is discussed in light of its feasibility and the associated economic opportunities and challenges. Although net-zero carbon is feasible from the get-go, results show that the promoter should identify opportunities to reduce as much as possible emissions at source, cooperate with other industries for CO₂ capture and utilization, replace natural gas from fossil sources by renewable sources and offset the remaining emissions by planting trees and/or buying offsets on the compliance and voluntary markets. As some of these solutions are still to be developed, to ensure timely net-zero pledge for the lifespan of the LNG plant, a portfolio and progressive approach to combine offsets and other options is preferable.

Keywords: carbon neutral; zero carbon; GHG source reduction; offset credit; large emitter

1. Introduction

Climate change induced by anthropogenic activities is one of the most challenging global environmental issues the international community has faced over the last 40 years. The Paris Agreement (in effect as of November 2016) invites countries to implement measures aiming at keeping the global temperature rise by 2100, well below 2 °C above pre-industrial levels and further restrain the temperature increase to 1.5 °C [1]. In 2018, the Intergovernmental Panel on Climate Change (IPCC) published a special report [2] on the mitigation of climate change. The report finds that limiting global warming to 1.5 °C calls for a transformation of the global economy and the swift implementation of drastic actions leading to a drop of the net anthropogenic emissions of circa 45% of the 2010 reference level by 2030, so as to reach “net-zero” by 2050. Although the actual estimates point to an increase in global temperature of >1.5 °C, the means to curtail climate change are there but require unprecedented changes worldwide [2–4].

The energy industry, due to fossil fuels consumption, is one of the economic sectors having the greatest impact on climate change [2], and therefore, efforts to move towards renewable energy supplies should be optimized worldwide [5–7]. Transition enticed greenhouse gas (GHG) emissions reductions are key but must be accompanied by a wide array of mitigation options, and investments in both strategies must be significantly increased [2,8].

In response, various groups of willing banks, companies and industries are associating, adopting policies and initiatives to decarbonize the economy [3,9–17]. The United Nations (UN) global compact is such an example where companies are invited to commit to the UN's Sustainable Development Goals (SDGs) notably in terms of GHG emissions and to set science-based targets (see [18]) in alignment with the 1.5 °C pathways, reaching net-zero emissions by 2050 [15]. Carbon neutrality or net-zero emissions entails that all anthropogenic GHG emissions, within a defined boundary (e.g., a building, a company, a city, a government, a country), are accounted for, reduced as much as possible and, as a last resort, balanced by carbon removal or offsets [2]. Therefore, every new source of GHG emissions hampers the chances for success of the Paris Agreement.

To achieve a global net-zero carbon footprint by 2050, any new GHG producing activity or industry should be carbon neutral from the beginning, reducing the pressure on an already challenged system [17,19–24]. New industrials wishing to abide by this rule often lack the understanding and knowledge of the scientific principles, rules and various regulations in effect, necessary to establish their potential carbon footprint and the means to erase it. Therefore, knowledge is scarce on the practical way to achieve this target from the get-go. We here present a case study of a potential future liquefied natural gas (LNG) plant to be built and operate in the Saguenay–Lac-St-Jean area, Quebec, Canada. The goal of the study was to determine if and how such a plant, as a predictable large Canadian GHG emitter, can be carbon neutral, outweighing each potential solution in terms of practicality and economic feasibility.

2. Materials and Methods

2.1. The Case Study

GNL Québec is a Quebec, Canada-based company in the LNG field, aiming to build and operate a natural gas liquefaction complex (project Énergie Saguenay, [25]) in the Grande-Anse, Saguenay port facilities (Figure 1). The plant, connected to Quebec's hydroelectric power grid, should include liquefaction equipment, storage facilities and marine shipment infrastructures. As the natural gas supply is sourced from western Canada, a new ~780 km long pipeline (under the responsibility of Gazoduq, inc., Montreal, Canada) is required to link the facility to the existing main gas pipeline system in Ontario [26]. The company expects to export 11 million tons of LNG per year offering transition energy of lower carbon footprint than fuel oils and coal to the European and Asian markets [25,27,28]. GNL Québec also aims for its liquefaction facility to be carbon neutral from the get-go, i.e., at the anticipated beginning of its operations in 2025 and for the duration of its operations [25]. In 2019, an environmental impact statement [27,28] comprising a life-cycle analysis (LCA) was performed by specialized third parties to meet both federal (Canada) and provincial (Quebec) governmental pre-approval assessment requirements. The process for the environmental impact assessment is currently in phase 3 [29,30].



Figure 1. Location of the proposed site for the natural gas liquefaction complex of the project Énergie Saguenay, GNL Québec (Saguenay, Quebec, Canada).

In Quebec, the Cap-and-Trade System (Système québécois de plafonnement et d'échange de droits d'émission; SPEDE), a compliance carbon market linked in 2014 to the Californian system within the Western Climate Initiative (WCI) framework, mandates that industrial emitters responsible for $>25,000 \text{ t CO}_2\text{-eq y}^{-1}$ offset all emissions above their allocated GHG emission units [31,32]. In accordance with Quebec's SPEDE's regulations, only direct GHG emissions—Scope 1 of the Énergie Saguenay project, i.e., the ones directly linked to the liquefaction facility activities per se are to be considered [32,33]. Emissions relating to natural gas extraction and transport are to be taken stock of and reported to the pertinent provincial ministry by the extracting company and pipeline owners, respectively [32,33]. Hydroelectricity provided to the plant by Hydro-Québec (crown corporation) falls into their own Scope 1 emission declaration to the SPEDE and are excluded from the Énergie Saguenay project GHG balance sheet to avoid double-entry [32,33]. Therefore, the organizational boundaries are circumscribed to the liquefaction complex and the reductions and/or offsets must match the pertaining future emissions, estimated in the LCA to be $421,000 \text{ t CO}_2\text{-eq y}^{-1}$ ($420,000 \text{ t CO}_2 \text{ y}^{-1}$ and $1000 \text{ t CO}_2\text{-eq y}^{-1}$ due to methane— CH_4) [27,32].

2.2. Methodology

To establish which credible means are available for the Énergie Saguenay project to be carbon neutral, a literature review was first performed. The aim of the literature review was to identify mitigation solutions available to industrials worldly, either as a potential for source reduction, substitution or offsets. The literature review identified mitigation solutions for the economic sectors of energy, agriculture, forestry, buildings, transport, industry as well as in geoengineering. Therefore, the aim was to present a wide perspective of solutions in order to allow and assist the promoter in selecting and prioritizing options adapted to its context. In this perspective, the method used to search for relevant material included qualitative and quantitative approaches. Peer-reviewed literature was searched from Scopus and Web of Science databases. The selection criteria of the iterative search were specified to extract literature reviews published between 2015 and 2019 in order to use the most recent research on the identified topics. Search strategy used first general terms: (CO_2 or

“carbon dioxide” or CO(sub2) or “greenhouse gas” or “greenhouse gases” or GHG) and (capture or sequestration or management or mitigation or reduction or offset or offset* or compensation or storage) and (application* or technolog* or solution*) and type=review and 2015–2019 and la=English. The second step was to extract articles from the first search from the domains of biological sequestration (“biological sequestration” or “biological carbon sequestration” or soil or soils or grassland* or forest* or peatland* or algae or algal or enzym*), geological sequestration (“geological sequestration” or “carbon capture and storage” or “carbon dioxide capture and storage” or “CO₂ capture and storage” or CCS or “carbon sequestration” or “underground injection” or “mineral sequestration” or “carbon capture and utili*ation” or CCU) and others, including geoengineering (geoengineer* or “planetary engineering” or terraform* or “climate engineering” or “climate remediation” or “climate intervention” or “atmospheric greenhouse removal” or “negative emissions technolog*”). All the articles were finally categorized based on their economic sector. Other peer-reviewed articles were also included based on their relevance to the identified topics and were not limited to a timeframe. Moreover, material from grey literature from recognized international organisms and other institutions (e.g., reports) was added when it was relevant with the topics. The outputs of this literature review are detailed and presented in the supplementary materials (Tables S1–S7).

Based on all the mitigation solutions found in the literature review and on the understanding of what a future LNG plant located in the Saguenay–Lac-St-Jean area involves, four more probable and applicable solutions were selected and prioritized with the promoter and further analyzed. Selection and prioritization were based on the context of the promoter regarding its location (e.g., access to feedstock and energy sources), social acceptability (e.g., offset quality—ex-post vs. ex-ante—and will to participate to local economy) and accessibility to local markets. Each was regarded in terms of its feasibility (technological maturity) and economic viability, concentrating on the challenges and opportunities it may represent. These selection criteria were chosen in order to achieve the pledge from the get-go for the lifespan of the LNG plant. Literature found for each solution as well as on the economic feasibility is detailed and presented in the supplementary materials (Tables S3 and S8–S10).

3. Results and Discussion

3.1. GHG Mitigation Solutions Available Worldwide: Outputs from the Literature Review

The literature review on worldly potential mitigation solutions resulted in a total of 239 relevant documents from the sectors of agriculture (26%), energy (21%), forestry (19%), geoengineering (14%), transport (11%), buildings (5%) and industry (4%) (Figure 2; Tables S1–S7). The lowest number of documents in the building (12) and industry (10) sectors is not a worry as these studies were mostly literature reviews and reports of various sources. All together, these mitigation solutions provide enough opportunities to reduce and capture GHG worldwide to achieve the -45% decrease by the 2030 objective [2,8].

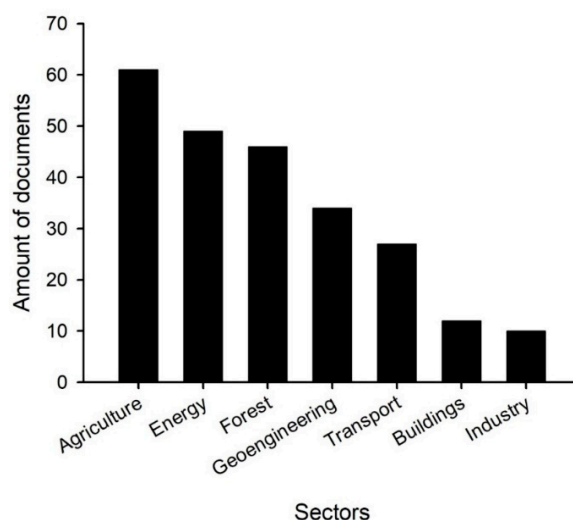


Figure 2. Amounts of relevant documents found in the literature review performed on credible means to reduce greenhouse gas emissions and to identify mitigation solutions available to industries globally, either as a potential for source reduction, substitution or offsets.

3.2. Potential Solutions for the Énergie Saguenay Project to Be Carbon Neutral

There are several solutions to achieve carbon neutrality for an industry and possibilities increase when GHG reductions and/or substitutions can be planned ahead of construction, relevant technology and potential synergies with other industrials being integrated in the projected plant's design, leaving offsetting options as the last resort. In the case of the Énergie Saguenay project, building and operating a LNG facility using hydroelectricity, a renewable energy, considerably lowers the carbon footprint of the LNG produced compared with a conventional LNG plant where the business as usual mode is to produce cooling and electricity with gas turbines ($0.022 \text{ kg CO}_2\text{-eq kWh}^{-1}$ for hydroelectricity compared to $0.685 \text{ kg CO}_2\text{-eq kWh}^{-1}$ for high voltage electricity from natural gas) [27,34]. However, in the case of the Énergie Saguenay project, supplied electricity are Scope 2 GHG emissions [33], which are outside of the project's boundaries; therefore, other means of achieving net-zero emissions must be used.

The four potential solutions to achieve carbon neutrality of the Énergie Saguenay project are presented and discussed in the following sections in terms of practicality and economic feasibility. Two of these solutions concern GHG reductions with CO_2 utilization and waste heat recovery as well as the substitution of natural gas from fossil sources with renewable natural gas from biogenic sources. The two remaining solutions consist of offsets by afforestation and carbon credits from the compliance and voluntary carbon markets.

3.2.1. CO_2 Utilization and Waste Heat Recovery

The Énergie Saguenay project expects to produce $420,000 \text{ t CO}_2 \text{ y}^{-1}$ as part of their process to purify the natural gas and remove traces of water, H_2S and CO_2 that could damage the liquefaction equipment during cooling, as well as from the natural gas vapors, usually flared [27]. Looking at this CO_2 as a byproduct from an industrial ecology standpoint, it represents an opportunity for the company as it falls in the new innovative field of carbon capture and utilization (CCU) (Table S8). CCU is one of the promising solutions to mitigate global warming [2,35,36] and the field is fast advancing, particularly in the development of new technology to utilize flue gas emissions [35,37–39]. There are numerous reviews, entire journals even, dedicated to the potential of CCU in the available pathways (direct use, mineralization, biological and chemical conversion) (Table S8).

Potential outputs for recovered CO_2 waste in the Énergie Saguenay project can be analyzed in terms of technology readiness level, cost effectiveness and available markets, but environmental and

GHG impacts also need to be addressed [9,38,39]. Finding local markets and distributing the CO₂ to third parties for recovery would benefit GNL Québec and its potential clients both economically and in its net-zero objective as the recovered CO₂ would be removed from its GHG annual declaration [32,40].

In addition to CO₂ recovery, waste heat (WHE) generated by the plant's operations can also be recovered and used within the facility or by third parties. Industrial waste heat recovery is another fast-evolving field (Table S8) with companies emerging to aid in the assessment of potential sources, available technology and economically sound solutions (the Canadian government bears a similar initiative [41]). As for the CO₂, there are many possible outputs for WHE, especially in industrial processes with high heat demand (Table S8). At least two avenues allow to combine both residual heat and CO₂, i.e., commercial greenhouses or algae cultivation (as fertilizers, biofuels or proteins, for example) [36]. In a carbon neutrality context, GNL Québec or the third party replaces or reduces its fossil fuel consumption by using WHE, carbon credits can be obtained if valid methodologies and protocols are strictly followed and credits' ownership is negotiated (otherwise they would solely apply to the third party) [1,33,42–44].

The plant design should include some flexibility to facilitate the installation of CCU and waste heat recovery technology in the future [45]. This would lower the discounted cost of retrofits [46] and give the firm the choice of integrating more suitable technology as they appear.

Market-related features of this option are the main unknowns. Few data on CO₂ prices are publicly available. Published price estimates are on the high side [47], but cost estimates vary widely [48]. The relevance of this option for the Énergie Saguenay project also depends on the provincial CO₂ market dynamics and features. The industrial gas market is a highly concentrated industry worldwide [49] and the local market dynamics are likely to be the same. Pursuing this option may require partnering with an existing player. On a positive note, with both CCU and waste heat recovery technology, a marketable end-product can help pay back the initial fixed costs and achieve carbon neutrality at a lower cost.

3.2.2. Renewable Natural Gas (RNG)

Natural gas to be liquefied at the Énergie Saguenay facility are projected to originate from fossil sources in Western Canada [27,28]. According to the performed LCA for the Énergie Saguenay project, which includes upstream emissions due to the natural gas life cycle and excludes downstream transport and final use, 91% of the expected GHG emissions (7858 kt CO₂-eq y⁻¹) are linked to the natural gas sourcing and transport to the LNG plant [50]. The GHG life cycle impact of the project can therefore be greatly affected and reduced by using, at least partially, natural gas produced from renewable sources [51]. As for Scope 1 Énergie Saguenay emissions resulting from RNG will be discounted as biogenic CO₂ is not considered in Quebec SPEDE. Biomethanisation (first generation technology), pyrolysis followed by a gasification (second generation) and pyrocatalytic hydrogenation (PCH, second generation) appears to be the most feasible mean to produce RNG (Table S9). Because of the plant's location in Quebec's boreal forest under exploitation, local biomass, namely logging residue, are of particular interest as feedstock for RNG [52,53]. Both pyrolysis with gasification and PCH can use this feedstock and are emergent technology operated at pilot scales (the first being tested locally in the Saguenay–Lac-St-Jean area to mainly produce biochar) with a potential to peak in 2030 [54–56]. Logging residue potential RNG yield has been estimated at 3089.3 million cubic meters for the Province of Quebec by that year [54].

By substituting part of its natural gas supply by RNG, GNL Québec could in theory generate carbon credits to reduce Énergie Saguenay's carbon footprint and meet governmental GHG reduction requirements. However, the SPEDE does not currently have a corresponding approved methodology, unlike the regulated carbon markets of Alberta and British Columbia [31,57–59]. Quebec's government has regulated nonetheless that natural gas suppliers should include 1% of RNG in 2020, 2% in 2023 and at least 5% by 2025 to notably stimulate technological advancements to use forestry biomass as feedstock [60]. It is not clear if Énergie Saguenay will have to comply with this regulation bylaw,

as they do not distribute natural gas in Quebec and planned customers are overseas. Carbon credits to be generated by RNG substitution will therefore in the worst case have to go above these mandatory thresholds and will have to be traded either on voluntary markets (or Alberta and British Columbia markets as voluntary participants) or claimed by clients on other markets. As each credit is serialized and unique, if the Énergie Saguenay project was to use the RNG credits to achieve carbon neutrality, then their buyers overseas could not use them to reduce their own footprints. As CO₂ extracted from the flue biogas is biogenic, it will proportionately reduce the plant accounted emissions by the same magnitude.

To operationalize the RNG option, an entire sub-industry has to be created, which, by itself, comes with risk. The inputs are a by-product of logging activities, which have been somewhat volatile over the last 30 years [61]. If RNG generation is outsourced, local business partners must be found to profitably generate and transport the gas, the value of the serialized credit. If RNG is generated internally, project risks (R&D, generation and transport) are wholly born by the firm. Some of this risk could be mitigated using creative capital financing with creditors [62]. The absence of an approved methodology for the process in the province—and more generally regulation uncertainty—is another type of risk that must be accounted for [46,63].

3.2.3. Afforestation/Reforestation

Once the technological in-house GHG reduction solutions to achieve net-zero for the Énergie Saguenay project have been exhausted, one can look at the possibility for large-scale tree plantations to capture the remainder of the produced CO₂ emissions (Table S3). Afforestation (per convention: whereby trees are planted on ≤25% canopy covered land since 1990 [64,65]) is a confirmed efficient low-cost tool in climate change mitigation [65,66]. Estimates of its global mitigation potential vary, ranging from ~3.2 Gt CO₂-eq in 2018 [67] to a potential of 42–205 Gt CO₂-eq, if deforestation was stopped and all available/suitable lands were covered by mature forests [66,68], being mindful of land competition and conversion, to avoid adverse consequences on other sustainable development goals [69,70].

Afforestation/reforestation are recognized activities that can generate carbon offset credits in the Kyoto Protocol, strictly following recognized methodologies [33,43,64]. Two types of forest credits can be obtained, ex-ante, where the credits are determined based on future CO₂ capture by the planted trees, and ex-post, calculated by the actual CO₂-stock net growth [43]. Models, such as CBM-CFS3 in Canada [71], evaluate carbon stocks based on tree species, location and growth yield. Serialized forest carbon credits are available to the Énergie Saguenay project through the WCI but not with the SPEDE as the Quebec government has no approved afforestation/reforestation methodology [31]. If GNL Québec wanted to create their own afforestation carbon credits in Quebec (as is their intention, pers. comm.), for now, these would have to be on voluntary markets unless regulations changed.

In the Province of Quebec, 1.7 million hectares of public land are suitable boreal open woodlands [72], of which only 10% is within 5 km of existing roads [73]. Private lands, mainly fallow lands (that were clear-cut for agriculture before 1990 [33]) represent only 3000 ha in the Saguenay–Lac-St-Jean area (Ministère de l’Agriculture, des Pêcheries et de l’Alimentation du Québec—MAPAQ, pers. comm.). Either for public or private land, authorizations must be granted by the relevant ministry (Quebec’s Ministère des Forêts, de la Faune et des Parcs—MFFP and MAPAQ, respectively), and key requirements of plantations’ additionality (the project sequesters more carbon than the “business as usual” scenario), permanence (must be maintained for 100 years) and non-leakage (must not cause a displacement of GHG emissions) must be observed ([33,43]). In addition, carbon credit ownership would have to be determined, as they usually belong to the proprietor of the land (be it government or farmers). Lastly, as the intent is for the Énergie Saguenay project to be carbon neutral starting 2025, plantations should begin promptly as the process to get forestry carbon credits is very involved (see [74] for example) and trees of the boreal forest are slow growing, capturing carbon accordingly (e.g., net sequestration rate of 4 t CO₂-eq ha⁻¹ y⁻¹ for planted black spruce (*Picea mariana* (Mill.)

B.S.P.) [75]). At least 27 years will, therefore, be necessary for the first ex-post verified credits to be available to offset the plant's GHG emissions, within the 25–50-year facility operational life expectancy [25,75]. Acquiring existing older plantations admissible as forest carbon credits could cut down waiting time, but the number of hectares necessary to capture the remaining CO₂-eq after reduction every year remains an issue. Thus, regardless of the tree species and its growth rate, it is not possible under present rules to offset a significant year-to-year portion of the GHG emissions using only afforestation projects in the Province of Quebec.

The global GHG mitigation potential of afforestation is estimated between 0.2–13.8 Gt CO₂-eq y⁻¹ in 2030 at costs of up to 100 USD t⁻¹ CO₂-eq [76]. Mitigation potentials of 0.01–1.45 and 0.11–9.5 Gt CO₂-eq y⁻¹ in 2030 can also be achieved at lower costs up to 20 and 50 USD t⁻¹ CO₂-eq, respectively [76]. Using provincial data [77], we estimate that afforestation cost in Quebec would be 2–15 CAD t⁻¹ CO₂-eq for public land and 2–13 CAD t⁻¹ CO₂-eq for private land. Estimates are slightly higher when using American data [78]. While afforestation cost makes it an interesting option, issues related to the access to the land and offset ownership remains to be addressed. Transaction costs [79] may be significant, especially for transactions involving private lands. Uncertainty related to offsets from afforestation comes hazard during tree growth (pests, wildfires) [80,81]. While these are easily observed ex-post, they must be accounted for at the beginning of the project; a riskier environment decreases the expected benefits associated with the option [82]. Given the regulatory and land availability constraints of offsets generated by afforestation, this option is to be used in conjunction with other methods.

3.2.4. Offsets

Once solutions to decrease GHG emissions or generate carbon credits have been exhausted, GNL Québec will need to acquire available offsets. Their use can amount to no more than 8% to meet SPEDE's regulatory compliance to, foremost, encourage reductions [31]. Five approved methodologies are in effect in Quebec, generating 813,763 t CO₂-eq available credits (in May 2020 [31]). After complying, carbon credits can be purchased on voluntary markets, usually through a broker, to achieve carbon neutrality. There are many different standards, methodologies and protocols used in voluntary carbon markets over the world (e.g., UN's Clean Development Mechanism, American Carbon registry, CSA group registries, etc.) and the types of GHG reduction projects realized, across all sectors, vary tremendously with associated varying co-benefits [64,83,84]. To help in the selection of projects/carbon credits, priorities should be determined and weighed before performing a multiple-criteria decision analysis. For example, GNL Québec may choose to mitigate their GHG emissions via credits generated in the province of their operations or favor specific SDG goals (e.g., reduce poverty, offer clean energy, increase biodiversity, etc.). In Quebec, projects are concentrated in the forestry, energy efficiency and waste disposal sectors (e.g., [85]).

Used with the other options explained above, carbon offsets serve as an outside option for GNL Québec. Provided no supply constraint comes into play, the market price for carbon offsets sets an upper bound to the cost of other abatement technology. Of course, other project-specific attributes will impact the choice of offsets the firm chooses, but that reasoning also applies to the general problem of choosing a portfolio of options. It is up to the firm to determine its priorities in achieving carbon neutrality. This is especially true as some options may be associated with externalities that must be priced and included in the project analyses.

One of the main interesting features of offsets is to link the offset price to allowance price. The floor price for allowances is established by the Province of Quebec [32]. With increases in the minimum price pegged to inflation, it provides a benchmark on which to evaluate the future abatement costs of the other options. However, offset and allowance prices are not necessarily perfectly correlated, with offsets being consistently cheaper than allowances in the European Trading Scheme (ETS). Some of this discrepancy is to be expected, as market linkages should lower the cost of reducing GHG emissions, but no convergence is to be expected given the inherent limits to the use of offsets in achieving

regulatory compliance [31]. Transaction costs [86] and different reaction to market fundamentals [87], as well as uncertainty, have been proposed to explain the gap [88].

3.2.5. Environmental and Social Implications of the Potential Solutions

For an LNG plant, achieving carbon neutrality from the get-go may have environmental and social implications other than climate change mitigation. The net-zero commitment is a voluntary pledge that implies investments and projects outside the boundaries of the Énergie Saguenay project itself. Therefore, this pledge is expected to have residual impacts other than those described in the environmental impact statement [27,28].

It is currently impossible to quantify potential impact displacement of being carbon neutral for Énergie Saguenay project. To do so, good practices would necessitate LCA studies as requested by ISO 14040 standard [89]. As the firm does not have a formalized planning to achieve its pledge from the get-go, and for the lifespan of the LNG plant, the available information is not sufficient. Thus, it is only possible at this stage to identify for each category potential implications and sensitive environmental components that may be impacted. For example, CCU, depending on the technology and products used for capture, distance to user, chemical processes and end use, may have implications in energy consumption, waste disposal, air and water pollutant emissions, land-use conflicts as well as employment. RNG, depending on the technology, may have implications on land-use change, aboriginal rights, water and biodiversity, air and soil quality depending on feedstock sustainability from agriculture or forestry. Afforestation may impact biodiversity, water cycle, land-use conflicts and soil conservation and restoration (e.g., carbon sequestration, limiting erosion). Offsets credits quality depends on the program (e.g., Verified Carbon Standard or Gold Standard) and location of projects. Ancillary environmental and social benefits may be anticipated but they would differ for renewable energy, industrial processes replacement, wetland restoration, agriculture or forestry credits in developed or developing countries.

In these conditions, it would be possible to assess net environmental and social benefits or impact displacements only after the firm would have determined its portfolio of measures to realize its pledge for a given year. However, as a general rule, as the governments of Quebec and Canada are committed to sustainable development and well-regulated for environmental and social protection, measures selected by the firm that can benefit local projects or offsets would be easier to document for this purpose and may be considered preferable overall.

3.3. Economic Perspective

Despite that offsets can bring environmental and social co-benefits, from an environmental perspective, it is always better to avoid emitting GHG [33,43]. Thus, the priority for the company should be at first GHG source reduction with CCU, waste heat recovery and RNG. Offsets by afforestation and carbon credits are the last choice solution. However, in reality, climate change is the perfect example of a market failure. The absence of a supranational authority to deal with the challenge means international cooperation is needed. However, the lack of coordination among countries leads to underfunding of clean initiatives.

To help solve the issues, economists long have promoted market options to ensure that private incentives are aligned with the public good: carbon pricing, either using cap-and-trade, a Pigovian tax or mix of tools allows for consumers and firm to internalize the environmental cost of GHG emissions. By pricing GHG, incentives are back in place to allow agents internalize the negative environmental externalities. With high GHG footprint goods become relatively pricier and agents substitute away from them. A lack of suitable substitutes, as indicated by low price elasticity of demand for high GHG footprint goods, will have to be associated with higher pricing to induce the necessary decrease to achieve an emission reduction target.

There remains some uncertainty surrounding the introduction of a new large emitter in Quebec. While the provincial emission reduction target is not supposed to be affected, new emitters are not

clearly accounted for in governmental GHG predictions, especially if they are to get free allowances. Depending on its abatement cost structure, a large emitter may have a non-trivial impact on auctioned allowance prices.

Since every emission is to be backed by an emission permit (allowance or offset), the firm faces a choice: lower its emission levels so that fewer permits are required or buy emission permits. When bidding for the auctioned allowances, an emitter's bid must reflect its underlying marginal abatement cost. If the final auctioned price is higher than a firm's bid, then it is more economical to abate emissions by adapting its manufacturing processes than to buy an offset.

For a large emitter in a new industry, there are regulatory uncertainties as to whether its emissions will be partially or fully covered by the SPEDE. A firm interested in becoming carbon neutral, with net-zero emissions, has to go above-and-beyond and find ways to compensate all its emissions. The nature of the problem is the same as in the compliance market: in equilibrium, the firm will reduce in-house emissions up to the point at which its marginal abatement cost equals the offset cost. A firm internal abatement costs are determined by studying all technically feasible options and by finding the associated costs and risks. Only then can the firm know more about its willingness to pay for allowances—and offsets. To find these practical options, the firm may get clues from top-down approaches, but as these generally lack the technical details necessary for small-scale decision-making, they will narrow down options using bottom-up approaches and internal and external resources. The final choice of abatement instruments requires careful financial analysis of abatement costs (investments and financing), risks and blend-in knowledge of the offset and allowance markets. In this context, a portfolio approach to abatement technology will be the key to minimize financial risk associated with becoming carbon neutral.

4. Conclusions

This study shows how a new major industrial GHG emitter starting its operation in 2025 in Quebec, Canada, could be carbon neutral for its Scope 1 emissions by compiling a net-zero carbon footprint from the get-go; in accordance with the Paris Agreement plan to stabilize the climate at +1.5 °C by the end of the century. The potential for GHG emission reduction and capture worldwide provide enough opportunities to achieve the −45% decrease by the 2030 objective. To be carbon neutral, the Énergie Saguenay project, led by GNL Québec, must put in place an array of cohesive strategies. Industrial ecology solutions with the sale of high-quality residual CO₂ and low carbon footprint heat geared towards other neighbored industries shows good potential. Replacing NG by RNG produced by pyrolysis of forestry residues also has a high potential, but technological hurdles remain as well as supply challenges. This solution may only be truly available past 2030 and cover only part of the reduction needs. Afforestation by the company is a good solution but with an effective timeframe of 2050 and is limited in actual conditions under Quebec regulations. Buying carbon offsets is essential, at least at the beginning of the liquefaction facility operations. Therefore, these options are all practically and economically feasible for GNL Québec to be carbon neutral although uncertainties remain. In this context, adopting a portfolio approach aligned with the evolution of the compliance and voluntary carbon markets is the most suitable approach to minimize the environmental and economic risks and ensure the success of the carbon neutrality objective. However, the success of maintaining this pledge over the lifespan of the LNG plant will depend on the firm willingness and economic constraints.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4433/11/8/810/s1>, Table S1: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the energy sector. Table S2: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the agriculture sector. Table S3: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the forest sector. Table S4: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the building sector. Table S5: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the transport sector. Table S6: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the industry sector. Table S7: References of the

literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in geoengineering. Table S8: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality in the sector of CO₂ utilization and waste heat recovery. Table S9: References of the literature review performed on the production and use of renewable natural gas as a credible mean to reduce greenhouse gas emissions and reach carbon neutrality. Table S10: References of the literature review performed on credible means to reduce greenhouse gas emissions and reach carbon neutrality regarding the economic feasibility.

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