frontiers | Frontiers in Energy Research

TYPE Original Research
PUBLISHED 23 September 2024
DOI 10.3389/fenrg.2024.1454862

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RECEIVED 25 June 2024
ACCEPTED 27 August 2024
PUBLISHED 23 September 2024

CITATION
Kostidi E and Lyridis D (2024) Social impact assessment of biofuel production for maritime and aviation sectors: a case study of a pilot biorefinery project.
Front. Energy Res. 12:1454862.
doi: 10.3389/fenrg.2024.1454862

Social impact assessment of biofuel production for maritime and aviation sectors: a case study of a pilot biorefinery project

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This work presents a comprehensive Social Life Cycle Assessment (S-LCA) and Social Cost-Benefit Analysis (S-CBA) conducted as part of a research project, studying biofuel production for the maritime and aviation sectors, from various types of non-food waste biomasses. The inclusion of social considerations complements and expands on the environmental and economic ones. The importance of social group criteria was determined through expert questionnaires, leading to the identification of social impacts groups and social criteria from stakeholders across participating countries. The results successfully identified and quantified social impacts, and align with those reported in similar cases in relevant literature. Social Cost-Benefits, monetarizing social factors, demonstrated several social benefits, including reduction in Greenhouse Gas Emissions. However, it also highlighted social costs, such as Economic Costs associated with the initial investment. The study revealed critical social hotspots within the impact categories, making significant strides in understanding the social impacts of biofuel production, providing valuable insights for decision-makers, and contributing to the broader goal of sustainable and socially responsible biofuel production.

KEYWORDS

social life cycle assessment, social cost-benefit analysis, biofuel, biorefinery, maritime, aviation, alternative fuel

1 Introduction

Sustainable alternative fuels are essential for reducing the environmental impact of aviation and maritime industries, meeting regulatory requirements, enhancing energy security, promoting innovation, and improving economic and environmental sustainability. They play a crucial role in addressing the pressing global challenges of climate change and air quality while driving positive economic and technological developments.

Biofuels can make a significant contribution as alternative fuels for aviation and maritime industries. However, it's important to note that the contribution of biofuels to aviation and maritime industries depends on various factors, including the availability of sustainable feedstock, technological advancements, and the development of supply chains and infrastructure. Additionally, the sustainability of biofuels depends on responsible sourcing practices to prevent negative impacts on land use, biodiversity, and food security (Groom, Gray, and Townsend 2008; Subramaniam et al., 2019; Tudge et al., 2021; Varela et al., 2022).

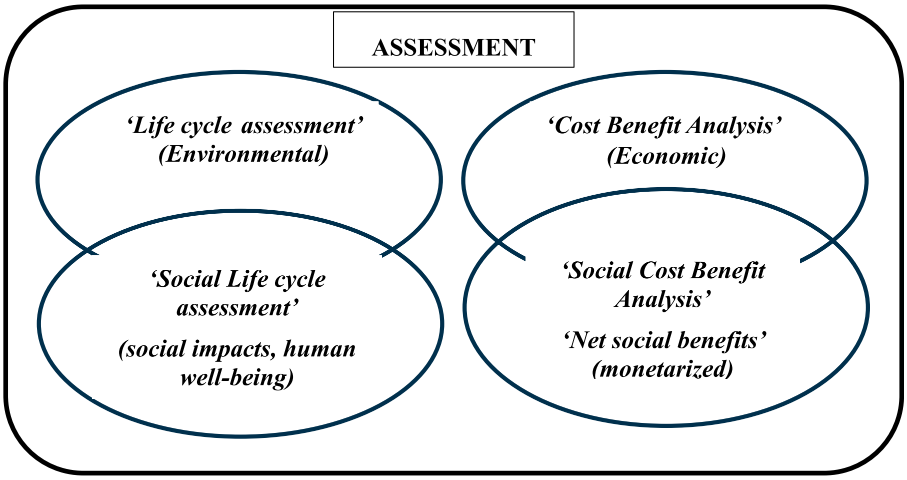

FIGURE 1
Expanding environmental and economic assessment.

To maximize the contribution of biofuels in aviation and maritime industries, it is essential, apart from responsible sourcing of feedstock, a holistic techno-economic assessment, market analysis, environmental as segment, social assessment and social cost-benefit analysis on a life cycle basis. Life cycle assessment (LCA) has generally been used to analyse the effects that a product or process will have on the environment. Results of an LCA study let the involved stakeholders know which aspects of their new developed product or process are efficient, and where that efficiency can be improved to reduce environmental impacts. The Social Life cycle assessment (S-LCA) is complementing the environmental LCA and Life Cycle Costing by adding extra dimensions of impact analysis, offering valuable information for those who seek to produce or purchase responsibly and by contributing to the full assessment of goods and services within the context of sustainable development. Social welfare is considered one of the main development goals of research projects promoting alternative fuel solutions (Rezaei Kalvani, Sharaai, and Abdullahi 2021; Meer, 2019). "Social Life Cycle Assessment" (S-LCA) and "Social Cost-Benefit Analysis" (S-CBA) are both methods used to evaluate the social impacts and benefits of products, projects, or policies (Pollok et al., 2021; Sureau et al., 2018; Scandizzo 2021; Kooten 2013). These approaches take into account various social factors and attempt to quantify their effects to aid decision-making and policy formulation.

Understanding and assessing what could improve or undermine wellbeing is a key element in developing sustainable fuel solutions, aiming at improving social and economic benefit while reducing both social and environmental impacts (Figure 1). Combining S-LCA and S-CBA studies into a united report is a comprehensive approach that can provide a holistic understanding of the social impacts and economic aspects of the BioSFerA project, (2024). Integrating S-LCA and S-CBA allows for a thorough examination of the project's life cycle and its implications on various social dimensions (Alomoto, Niñerola, and Pié 2022; Hertel, Bacq, and Lumpkin 2022; Zamagni, Pesonen, and Swarr 2013).

The main research questions and hypotheses that guide the social impacts and economic aspects in this work are.

- What are the social and socio-economic impacts of producing biofuels from various types of non-food biomass and at different biorefinery locations, in comparison to conventional fossil fuels?
- How can the S-LCA and S-CBA methodologies be utilized to measure and value the social and socio-economic impacts of biofuel production?
- How can the social and socio-economic impacts of biofuel production be incorporated into the sustainability assessment of the process, and how can this information guide policy and decision-making?

The article begins with a brief overview of the theoretical framework for social assessment and social cost-benefit analysis. This is followed by a detailed presentation of the methodology used in the study. The subsequent section delineates the system boundaries of the selected case-studies. The focus then shifts to the criteria and indicators used in the Social Life Cycle Assessment. An analysis of social costs and benefits is carried out next. The penultimate section presents the results and engages in a discussion of their implications. The article concludes with a summary of the conclusions drawn from the study.

2 Brief theoretical framework of social assessment and social cost-benefit analysis

2.1 Potential of biofuels to reduce GHG emissions

The maritime and aviation industries play a pivotal role in global transportation and trade, yet they are significant contributors to greenhouse gas (GHG) emissions. While these sectors have experienced substantial growth in recent decades, driven by increasing passenger numbers and trade volumes, their emissions have grown at an alarming rate (‘Emissions from Planes and Ships: Facts and Figures (Infographic)’ 2019). Biofuels can play a critical role in mitigating GHG emissions in the maritime and aviation sectors due to their renewable nature and lower lifecycle emissions compared to fossil fuels. For instance, biofuels produced from non-food waste biomass, such as agricultural residues, municipal solid waste, and industrial by-products, can achieve a substantial reduction in GHG emissions. Studies have shown that using biofuels can result in up to 80% reduction in lifecycle GHG emissions compared to conventional petroleum-based fuels (IEA, 2024).

The BioSFerA project seeks to develop a cost-effective, interdisciplinary technology for producing sustainable aviation and maritime fuels. This process involves converting biogenic residues and wastes into syngas through gasification, followed by fermentation to create bio-based triacylglycerides (TAGs). These TAGs will then be transformed into biofuels via hydrotreatment. The project aims to advance the technology from Technology Readiness Level (TRL) three to TRL five through rigorous lab-scale testing and subsequent pilot-scale validation. Comprehensive techno-economic, market, environmental, social, and health and safety assessments will be conducted to evaluate the overall feasibility and impact of the technology.

Kourkoumpas, Bon, et al. (2024) in their study (as part of BioSFerA project) demonstrate the significant potential of biomass-to-liquid (BtL) biofuels to reduce greenhouse gas (GHG) emissions in the aviation and maritime sectors. By employing a comprehensive Life Cycle Assessment across multiple scenarios, they found that substituting conventional fossil fuels with BtL biofuels could lead to substantial GHG reductions, ranging from 60% to 86%. This reduction according to the authors is primarily attributed to the biogenic carbon content of the biofuels, which offsets a significant portion of the emissions generated throughout the biofuel lifecycle. These findings provide strong evidence supporting the environmental benefits of BtL biofuels for the aviation and maritime sectors. By optimizing feedstock selection, biorefinery location, and electricity mix, the potential for GHG emission reductions can be maximized. Biofuel production offers a suite of social benefits that complement its environmental advantages. From reducing greenhouse gas emissions to creating jobs and reducing foreign oil dependence, biofuels represent a sustainable path forward for both society and the planet.

However, transitioning to biofuels is not without its challenges and requires a comprehensive approach to ensure environmental benefits are maximized while addressing social implications. By utilizing non-food waste biomass, biofuel production avoids competition with food crops and associated land-use change emissions. This is critical to ensure sustainability and minimize potential negative social impacts (Erauskin-Tolosa et al., 2021). Social Life Cycle Assessment (S-LCA) and Social Cost-Benefit Analysis (S-CBA) are valuable tools for assessing the broader impacts of biofuel production. S-LCA evaluates the social and socio-economic aspects throughout the lifecycle of biofuels, including impacts on workers, local communities, and overall societal wellbeing (Benoît-Norris et al., 2020). S-CBA, on the other hand, incorporates social considerations into economic evaluations, balancing the costs and benefits to ensure projects contribute positively to social welfare (Bouillass, Blanc, and Perez-Lopez, 2021).

2.2 Social effects of a biorefinery project

The drive towards biofuels, such as ethanol and biodiesel, stems from their potential to significantly reduce greenhouse gas emissions. Ethanol, for instance, can cut emissions by up to 65%, while biodiesel made from cooking oil can reduce them by as much as 87% compared to petroleum diesel (Datta et al., 2024). Beyond their lower carbon footprint, biofuels are less flammable than fossil diesel and offer superior lubricating properties, which can enhance engine performance (Rist et al., 2009).

The social implications of biofuel production are profound and multifaceted. One significant benefits is the reduction in foreign oil dependence. This shift has been recognized on both sides of the Atlantic for its potential economic and security advantages (Jeswani, Chilvers, and Azapagic 2020). In the U.S., the government has acknowledged that biofuels can reduce the need to import petroleum fuels, thereby enhancing national security and economic stability (Northern Ireland Assembly 2008). Similarly, the European Commission has noted that biofuels can improve the EU’s security of supply and reduce greenhouse gas emissions (Pryshliak and Tokarchuk 2020; Vackeová and Noyon 2022).

Job creation is another cornerstone of the social benefits associated with biofuel production. The construction and operation of biorefineries create a spectrum of employment opportunities across various sectors, including research and development, design and construction, feedstock production, biorefinery operation, sales, and distribution (Malik et al., 2024). This local employment not only contributes to economic development but also fosters skill development within communities. Estimating job creation from biofuel projects is complex and varies across studies (IRENA 2017). However, it’s clear that biofuel production can create a significant number of direct, indirect, and induced jobs. For example, the AFTER-BIOCHEM project anticipates creating 60 direct jobs and up to 200 indirect jobs in manufacturing and construction/engineering sectors (New Report Shows Advanced Biofuels Industry Can Create Jobs, Economic Growth’ 2009).

The transition towards biofuel production, particularly for aviation and maritime sectors, carries with it a range of social costs that must be carefully considered. These costs are not only direct, such as those associated with labor and materials for production but also indirect and external, affecting related industries and the environment.

One significant concern is the competition for resources. As biofuels require materials that could otherwise be used for composting or animal feed, there is a potential conflict in resource allocation (Searchinger and Heimlich, 2015). The environmental impact of biofuels is another critical factor; while they can reduce greenhouse gas emissions, their production process may lead to other environmental issues (Kourkoumpas, Bon, et al., 2024). Social displacement is a potential consequence as communities may be uprooted due to land acquisition for biofuel crops (Van der Horst and Vermeylen, 2011). Similarly, food security concerns arise when agricultural by-products are diverted from food production to biofuel production, which could strain food supply chains ('Biofuels - Energy System', n.d.). The creation of jobs in biofuel production might be offset by job displacement in traditional energy sectors (Harvey and correspondent, 2022). Additionally, the health impact on local communities cannot be overlooked, as production processes may lead to air or water pollution with significant health implications (Popp et al., 2016).

However, it's worth noting that biofuel production from non-food waste such as pellets, straw, pruning from vineyards and olive groves, and organic waste is expected to have minimal social costs due to the nature of the feedstock and its small scale. On the other hand, biofuel production offers a suite of social benefits that complement its environmental advantages. From reducing greenhouse gas emissions to creating jobs and reducing foreign oil dependence, biofuels represent a sustainable path forward for both society and the planet. Balancing economic growth, environmental stewardship, and social wellbeing is essential for the successful implementation (Solarte-Toro and Cardona Alzate 2023; Santos et al., 2024).

S-LCA and S-CBA can help the organization deliver its mission-critical services, engage its communities, and increase trust among stakeholders. S-LCA is a method that assesses the social and socio-economic impacts of a product throughout its life cycle, from raw material extraction to disposal (Mattioda et al., 2020). On the other hand, S-CBA is a method that compares the social costs and benefits of a project or policy, taking into account the externalities that are not reflected in the market price (Zhang et al., 2021). When considering the use of biofuels as marine and plane fuel, S-LCA can be used to assess the social impact of the entire life cycle of biofuels, including the social impact of the raw material extraction, processing, transportation, and use of biofuels. S-CBA can be used to compare the social costs and benefits of using biofuels as marine and plane fuel with those of using conventional fossil fuels, taking into account the externalities such as environmental effects.

2.3 Social Life Cycle Assessment

Social Life Cycle Assessment (S-LCA) is a powerful technique to assess and report about the social and socio-economic impacts and benefits of product life cycle from the extraction of the natural resources to the final disposal (Benoît-Norris et al., 2020). It helps organizations to measure and manage social risks within their supply chains. The guidelines for S-LCA of products provide an adequate technical framework from which a larger group of stakeholders can engage to move towards social responsibility when assessing the life cycle of goods and services. S-LCA is important because it provides a comprehensive approach to evaluate the social impacts of products and services, which is essential for sustainable development.

According to the literature analysis conducted by (Ramos et al., 2020), the prevailing patterns indicate a surge in interest in Social Life Cycle Assessment studies within the context of the bioeconomy. This observation suggests a mirroring of trends seen in broader sustainability science, with a notable resonance in the field of social sustainability. The authors further assert that, despite more than 2 decades of development, S-LCA is currently experiencing its most flourishing period. However, they also acknowledge that there is a considerable distance to cover before achieving the scientific maturity of this assessment methodology.

In order to choose the social impact criteria, this study adopted the criteria provided by Society of Environmental Toxicology and Chemistry (SETAC)/United Nations Environment Programme (UNEP) Code of Practice (Blom and Christine, 2009), supplemented by a survey, and reconciled by literature review. The criteria were grouped by (Manik, Leahy, and Halog 2013) as: 1. Human Rights 2. Working Conditions 3. Cultural Heritage 4. Socio-economic Repercussion 5. Governance. Each criterion represents a different aspect of social sustainability, and together they provide a comprehensive framework for evaluation.

2.4 Social cost-benefit analysis

Social Cost-Benefit Analysis (S-CBA) is a systematic and comprehensive approach used to evaluate the efficiency of a project from the perspective of the society as a whole. It involves identifying, measuring, and comparing all the costs and benefits of a project, policy, or decision. CBA is a compass in the decision-making process, guiding efforts toward interventions that not only align with the intended objectives but also offer the best returns on investment. It empowers policymakers and stakeholders to make data-driven choices, optimize resource allocation, and enhance the overall effectiveness of public interventions in the face of pressing challenges like climate change and development.

The economic evaluation of a project performed with the use of a Cost Benefit Analysis to assess whether a project or policy should be undertaken or not, could also be improved with use of complement methodologies to evaluate the welfare of the economic results. Social cost-benefit analysis (S-CBA) is an extension of the economic CBA, adjusted to take into account the full spectrum of costs and benefits (including social and environmental effects) accepted by society as a whole as a result of an intervention. In order to compare different types of costs and benefits with economic costs and benefits, they must first be converted in monetary values. The condition for a project or process to be undertaken is that the sum of economic, social and environmental benefits outweighs the sum of economic, social and environmental costs. The S-CBA used to evaluate the developed biofuels of the project will identify the targeted population who gain and (if there are any) those who lose, will identify the benefits and costs of the new alternative fuels allocated to time periods, will quantify the benefits and costs within ranges and will compare the estimated benefits with costs to a discounted common period. The S-CBA will incorporate social considerations into the cost–benefit analysis providing a framework for combining 'wellbeing' impacts into the socio-economic benefits of the alternative fuel solutions.

Social cost-benefit analysis is much broader in scope than private cost-benefit analysis because it considers what constitutes valid measures of wellbeing, of costs and benefits it, taking into account the effect that projects have on all facets of society–on all citizens (Kooten, 2013). The short answer is that economists measure costs and benefits as surpluses; the longer answer requires some elaboration. Social cost-benefit analysis assumes that everything of interest to the decision maker can somehow be measured in monetary terms (Bonner, 2022). Nevertheless, there remain some things of importance to society that simply cannot be included in the money metric. Since these items are only important if they are somehow (directly or indirectly) affected by the project, these 'intangibles' must be evaluated or judged against the money metric. If the focus is on employment (which is not a true surplus) than any gain in employment that a policy or project brings about needs to be evaluated in terms of the net social loss, preferably measured in terms of the forgone opportunities per job created. If the focus is on CO2 emissions, a project that reduces the amount of CO2 in the atmosphere needs to be evaluated with respect to the change in a society's 'surpluses' (economic wellbeing broadly defined).

There are two principal approaches for the quantitative assessment of the costs and benefits to society to determine if an investment will have greater value for society than not making it. The Little-Mirrlees (L-M) Approach and the UNIDO Approach (Borad 2021). The first approach was is based on the concept of shadow pricing, and the second on the other hand, is a more recent development and is based on the concept of social opportunity cost. Shadow Price is the real economic price of projects, activities, goods, and services that have no market price or for which prices are difficult to estimate. It is the opportunity cost, i.e., what somebody had to give up when they made a choice. The shadow price is often defined by what somebody has to give up to gain an extra unit of that good. However, the value of a good or project when measured using the shadow price may differ from its value when measured using market prices. This is because the market may not have properly priced it in the first place. On the other hand, Opportunity Cost is a more general concept that refers to the value of the best alternative forgone, where a choice needs to be made between several mutually exclusive alternatives under conditions of scarcity. It's the value of the next best alternative use of the resources. While both terms refer to the cost of forgoing the next best alternative, shadow price is specifically used to estimate the real economic price of goods or projects that do not have a market price or are hard to value, whereas opportunity cost is a broader term used in decision-making processes to consider the cost of forgoing the next best alternative. Given that the BioSFerA project aims to develop a cost-effective interdisciplinary technology to produce sustainable aviation and maritime fuels, it might involve both types of situations. Therefore, a combination of both approaches could potentially be used, depending on the specific aspects being analysed.

By using these methods, it is possible to evaluate the social impact of biofuels as marine and plane fuel and make informed decisions that take into account the social, economic, and environmental aspects of the use of biofuels.

3 Methodology

3.1 Social Life Cycle Assessment

Social impacts are typically measured through a systematic process that involves the identification, prioritization, and evaluation of various social and socio-economic impact subcategories (Bouillass, Blanc, and Perez-Lopez 2021).The S-LCA process typically involves several key steps (Benoît-Norris et al., 2020): Identification of Impact Subcategories, Prioritization of Impact Subcategories, Selection of Indicators, Data Collection, Evaluation of Social Impacts, and finally Interpretation of Results.

In the context of the BioSFerA project, the S-LCA would aim to assess the social impacts of producing biofuels for aviation and maritime sectors from different types of non-food biomass. The assessment would consider impacts on workers' rights and conditions, local communities, socio-economic development, health and safety, and cultural heritage. To conduct a social cost-benefit analysis for the BioSFerA project, it is needed to assess the viability of the project for the public and not just for shareholders. It is also needed to identify and measure the economic as well as social costs and benefits of the project and investment.

3.2 Social cost-benefit analysis

The S-CBA incorporate social considerations into the cost-benefit analysis, providing a framework for integrating 'wellbeing' impacts into the socio-economic benefits of alternative fuel solutions.

A brief overview of the key components of S-CBA are: Identification of Costs and Benefits, Measurement of Costs and Benefits, Comparison of Costs and Benefits, and analysis.

By carrying out a S-CBA, a project may ensure that it not only contributes to energy security and environmental sustainability but also maximizes social welfare. This holistic approach can help to build a more sustainable and inclusive bioeconomy.

3.3 Trade-offs and synergies between the environmental, social, and economic dimensions

The S-LCA follows the ISO 14040 framework and the UNEP Guidelines, and assesses the social impacts of the biofuels production along the life cycle stages, such as feedstock cultivation, transport, conversion, and end-use. The S-CBA incorporates social considerations into the cost–benefit analysis, and provides a framework for combining 'wellbeing' impacts into the socio-economic benefits of the alternative fuel solutions. The combined methodology involves a series of steps designed to ensure a comprehensive evaluation of social and socio-economic impacts.

The process begins with the Identification of Impact Subcategories and Costs and Benefits, where various social, socio-economic, and wellbeing impact subcategories are identified. This is followed by the Prioritization of Impact Subcategories, ensuring that the most significant areas are addressed. Subsequently, relevant Indicators are selected to measure these impacts.

Data Collection is then undertaken to gather necessary information, which allows for the Measurement of Costs and Benefits. This data serves as the foundation for the subsequent Evaluation of Social Impacts and Comparison of Costs and Benefits, where the collected data is analyzed to assess the viability of the project not only for shareholders but also for the public.

Finally, the process culminates in the Interpretation of Results, where insights are drawn from the evaluation to inform decisions. This holistic approach ensures that projects contribute to energy security, environmental sustainability, and maximize social welfare, thereby fostering a sustainable and inclusive bioeconomy.

Combining S-LCA and S-CBA allows for a robust evaluation of biofuel production projects, ensuring that they are sustainable, inclusive, and beneficial to society as a whole. This integrated approach not only addresses the economic viability of projects but also ensures that social and environmental impacts are thoroughly assessed and considered in decision-making processes.

4 The BioSFerA case studies

The case studies are based on an establishment of a 200 MWth plant, that corresponds to feedstock annual needs of approximately 250 kt/year (considering LHV of 20 MJ/kg and annual operational time of 6,000 h). Case study scenarios were configured, focusing on different feedstocks and biorefinery locations (Kourkoumpas, Bon, et al., 2024): 1) Greece–Case 1 (20/80% w/w dry matter basis organic waste/olive tree pruning), 2) Greece–Case 2 (Olive tree pruning), 3) Finland (Logging and wood residues), 4) Italy (Straw-derived residues), and 5) Spain (Vineyard pruning).

4.1 Boundaries of system

The functional unit provides the reference to which the inputs and outputs of the systems are normalised. The production of biofuel from non-food biomass involves several stages, each with its own potential hotspots or areas of concern. Here are some of them Figure 2.

Feedstock Processing: This involves the conversion of biomass into a useable form for biofuel production. Hotspots can include energy use and emissions from processing.

Biofuel Production: This is the conversion of processed biomass into biofuel. Hotspots can include energy use, emissions from production processes, and waste generation.

Distribution and Use: This involves the transportation and use of biofuels. Hotspots can include emissions from transportation and combustion.

Producing biofuel from non-food biomass such as pellet, straw, pruning (vineyard and olive), and organic waste can help mitigate some of these hotspots. For instance, using these types of biomass can reduce competition with food crops and may require less water and fertilizer. Moreover, using waste materials for biofuel production can contribute to waste management solutions.

However, it’s important to note that while these approaches can mitigate some of the hotspots, they also have their own set of challenges, such as the need for advanced technologies for biofuel production from these feedstocks. Therefore, a balanced and sustainable approach is needed in the development and use of biofuels.

4.2 Social Life Cycle Assessment criteria and indicators

The social impact criteria used in this study, were adopted from the criteria provided by Society of Environmental Toxicology and Chemistry (SETAC)/United Nations Environment Programme (UNEP) Code of Practice (Blom and Solmar 2009), supplemented by a survey, and reconciled by literature review Figure 3.

1. Human Rights: Corporate Finance Institute (2024) this criterion emphasizes that sustainable development includes the rights to life, health, food, water, sanitation, and gender equality, and that a safe, clean, healthy, and sustainable environment is integral to the full enjoyment of these rights (About Human Rights and the Environment, n.d.; Corporate Finance Institute, 2024; Gupta et al., 2019).
2. Working Conditions: This criterion underscores the importance of labor relations, fair wages, working hours, and the right to collective bargaining in social sustainability. It also highlights the need for businesses to manage their impacts on employees, workers in the value chain, customers, and local communities proactively (World Employment and Social Outlook: Trends 2024, 2024; Gupta et al., 2019).
3. Cultural Heritage: This criterion aligns with the understanding that sustainability involves the impact of projects on the cultural heritage of the communities where they operate. It suggests that it is possible to identify indicators and match them with verifier variables to support the inclusion of social and cultural values in planning (Axelsson et al., 2013).
4. Socio-economic Repercussion: This criterion refers to the social and economic impacts of projects on local communities and the wider society. It emphasizes the importance of a participatory approach in defining strategies, policies, initiatives, services, and products, as well as in defining agreed objectives to secure a good life now and for future generations (McGuinn, 2020).
5. Governance: This criterion underscores that good governance is crucial for the success and sustainability of projects. It provides direction, defines procedures and processes, and creates a framework for decision making. It also enables greater transparency and visibility across the project landscape, ensuring that the project is well managed and that stakeholders are kept informed of progress (Matthews 2019).

Since indicators are essential tools for assessing, managing, and communicating about the social impacts and benefits of a project, the following indicators were chosen.

1. Gender Equity: This refers to the fair treatment of all genders in the biofuel production industry, ensuring equal access to opportunities, resources, and benefits (Rossi and Lambrou 2008).
2. Occupational Health and Safety: This involves implementing policies, procedures, and practices to protect workers in the biofuel industry from hazards that could cause injury or illness.
3. Work-Life Balance: This refers to the equilibrium between work responsibilities and personal life for biofuel producers, taking into account the potential for long or irregular hours in this industry.
4. Job Satisfaction and Engagement: This involves ensuring high levels of job satisfaction and engagement among biofuel producers, which can contribute to a motivated, productive, and stable workforce.
5. Community Engagement: This refers to the involvement of local communities in decision-making processes related to biofuel production and their perceptions of the project.
6. Public Commitments to Sustainability Issues: This refers to the commitments made by the organization to address sustainability issues in biofuel production.

The chosen indicators for assessment under the corresponding group category are listed in Table 1.

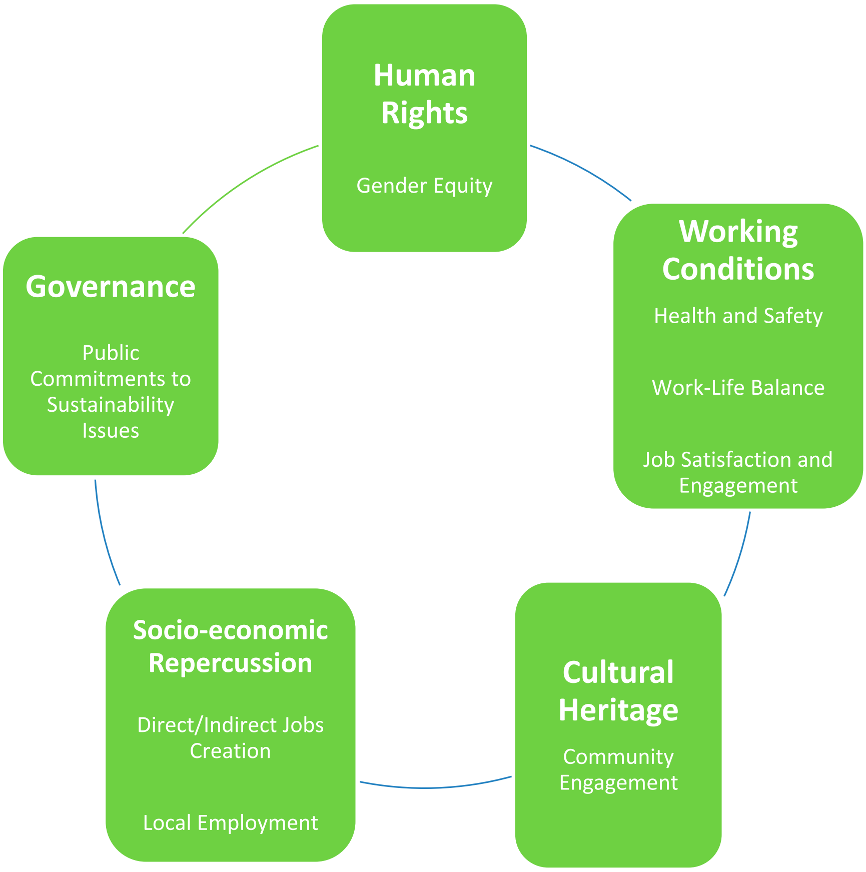

FIGURE 2
Indicators for the assessment under the corresponding group category.

TABLE 1 The chosen indicators for assessment under the corresponding group category.

Human Rights
◦ Gender Equity
Working Conditions
◦ Health and Safety
◦ Work-Life Balance
◦ Job Satisfaction and Engagement
Cultural Heritage
◦ Community Engagement
Socio-economic Repercussion
◦ Direct/Indirect Jobs Creation
◦ Local Employment
Governance
◦ Public Commitments to Sustainability Issues

4.3 Social life cycle costs and benefits for the BioSFerA project

Like in the cost-benefit analysis the sum of the social costs is deducted from the social benefits to get the net social benefit to the society.

The costs associated with biofuel production apart from the initial plant investment mainly are.

$$\text{social benefits} - \text{social costs} = \text{net social benefits to the society}$$

- ➢ Collection and Transportation: Cost of transportation and logistics for waste collection and fuel distribution.
- ➢ Processing: The processing costs for the biofuel production.

4.3.1 Monetizing cost-benefit

Before contacting social cost-benefit analysis, it is necessary to estimate the monetary values of the factors assessed. Since most of the social costs and benefits are not pushed like the touchable products or services, it is necessary to monetarize them. Assigning monetary value to the benefits of biofuel production involves quantifying the external costs of greenhouse gas (GHG) emissions, such as damage to crops, healthcare costs from climate-related disasters, and property loss due to flooding and sea-level rise. These costs are often internalized through carbon pricing mechanisms like the EU Emissions Trading System (EU ETS), which operates on a 'cap and trade' principle and has seen emission allowance prices reach up to 100.34 euros per metric ton of CO2 in February 2023.

The value per tonne of CO2 reduction varies based on calculation methods and context. For instance, savings from reduced oil imports due to biofuel production can be substantial. If biofuel production decreases oil imports by one million barrels per day at $100 per barrel, the savings amount to $100 million daily, equating to over $36 billion annually. Moreover, reducing oil dependence can enhance national economic stability by improving trade balances and mitigating risks associated with oil price volatility and supply disruptions.

Job creation from biofuel projects also holds monetary value. The economic contribution of these jobs can be measured by the wages and benefits paid, making such projects more appealing to investors ('Employment Growth and the Establishment of Bio-Refineries in the EU', 2020).

5 Analysis of the results

5.1 Social Life Cycle Assessment results

The importance of social group criteria was determined through expert questionnaires, leading to the weighting of social impacts groups. 15 Experts answered the questionnaire, equally distributed among the participating countries. They were asked to weight the importance of each of the social group criteria (i.e., Human Rights, Working Conditions, Cultural Heritage, Socio-economic Repercussion, and Governance), in a scale 1 to 10 (1 for the lowest).

Another similar questionnaire was circulated to evaluate the social indicators under each social group criteria (Table 1) from stakeholders across participating countries. The social indicators were ranked in a scale 1 to 10 according to each relevance. 33 questionnaires were collected. Care was taken to include all categories of stakeholders across participating countries. Descriptive statistics (mean, median, standard deviation) were calculated for each indicator. Cronbach's Alpha, calculated using SPSS, yielded a value of 0.822, indicating high internal consistency among the items.

5.1.1 Social sustainability criteria weighting

Social impact categories were weighted by experts according to their importance, using a 1–10 scale, (1 is the lowest importance and 10 the highest).

The mean social impact group categories weight is shown in Figures 4. Mean social group criteria weighted. The weight on the importance of the social group criteria is almost similar within the project participating countries, and high, or almost high (Figure 5). The less weighted criterion is Cultural Heritage.

5.1.2 Social indicator assessment

The social indicators ranked in the collected questionnaires were weighted by multiplied by the corresponding social group criterion weight. The results are shown in Figure 6 . The survey revealed the critical social hotspots within the impact categories to be addressed through actions. The main found concern is Health and Safety. Attention is also needed in the public commitment and Community Engagement.

5.2 Social life cycle cost-benefit assessment results

5.2.1 Initial investment

The initial investment in a biorefinery itself is not directly a social cost, but it can have social consequences and the investment is necessary in order to get the benefits. The Total Capital Investment, for the case study establishment of a 200 MWth plant, is 580,000,000 € (Detsios et al., 2024).

5.2.2 Job creation

The labor costs for every case scenario has been estimated in Detsios et al. (2024). As mentioned in 4.3.1 it may be measured by the economic contribution of these jobs, and for the case biorefinery is 3,500,000 €/year.

5.2.3 Environmental cost-benefit

Life Cycle GHG emissions associated for the five scenarios investigated (Kourkoumpas, Bon, et al., 2024) are presented in Table 2.

Based on the RED II (Annex V, part B in paragraph 19) "For biofuels used as transport fuels, the total emissions saving compared to the fossil fuel shall be 94 gCO2eq/MJ" (EU-ETS Price 2022–2024, n.d.).

For the cost-benefit analysis GHG emissions associated with the production of fuel are regarded as costs, and the GHG emission savings are the benefit. The emission amounts were monetarized using the price of emissions allowances (EUA) traded on the EU ETS 100.34 euros per metric ton of CO2 in February 2023.

The results are presented every case study in Figure 7. It is obvious the benefit from not using conventional fuel (in monetarized GHG emissions) it is much greater than the cost (in monetarized GHG emissions) for the production of the biofuel.

6 Conclusion

The present task of the BioSFerA Project, with its focus on producing biofuels for aviation and maritime sectors, has undertaken a critical mission: to assess the social viability of these alternative fuel solutions. Through a rigorous Social Life Cycle Assessment (S-LCA) and Social Cost-Benefit Analysis (S-CBA), the project has shed light on the multifaceted social impacts of biofuel production from non-food waste.

Utilizing the robust S-LCA method, this study evaluated the social impacts of a product's life cycle. The aim was to aid organizations in managing social risks within their supply chains and promoting social responsibility. The social impact criteria were developed in accordance with the SETAC/UNEP Code of Practice and were further refined through a survey and literature review. These criteria covered various social groups, including Human

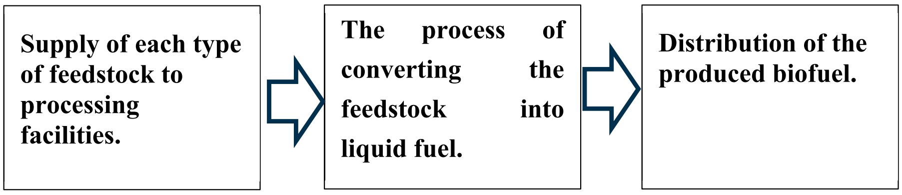

FIGURE 3
The boundaries of the system.

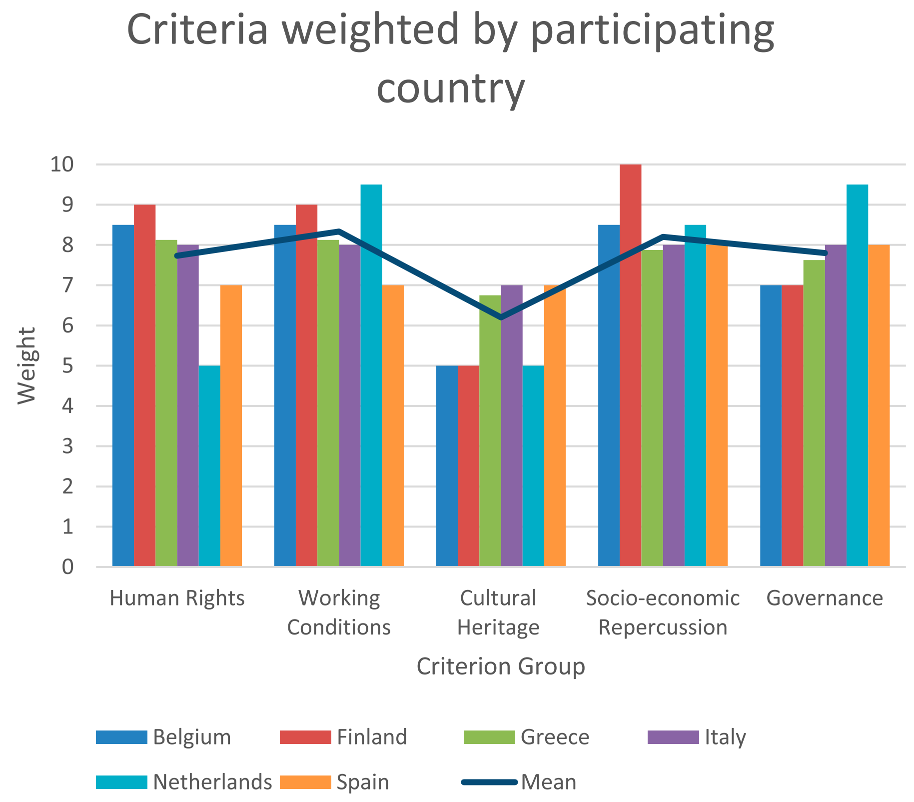

FIGURE 4
Social group criteria weighted by country.

TABLE 2 Life Cycle GHGe emissions associated with the scenarios investigated.

	Emissions (g CO2eq/MJ)				
	Greece Case 1	Greece Case 2	Finland	Italy	Spain
Total GHG (production) emissions	38	25.6	15.5	24.8	16.7
GHG emissions saved	56	68.4	78.5	69.2	77.3

Rights, Working Conditions, Cultural Heritage, Socio-economic Repercussion, and Governance, thus providing a comprehensive evaluation framework. Each of these groups represents a unique facet of social sustainability, and specific indicators were chosen for assessment. For the Human Rights group, the focus was on ensuring Gender Equity, a fundamental human right. The Working Conditions group included measures and practices to ensure Health and Safety, Work-Life Balance, and Job Satisfaction and Engagement. The Cultural Heritage group emphasized Community Engagement to ensure the involvement of local communities in

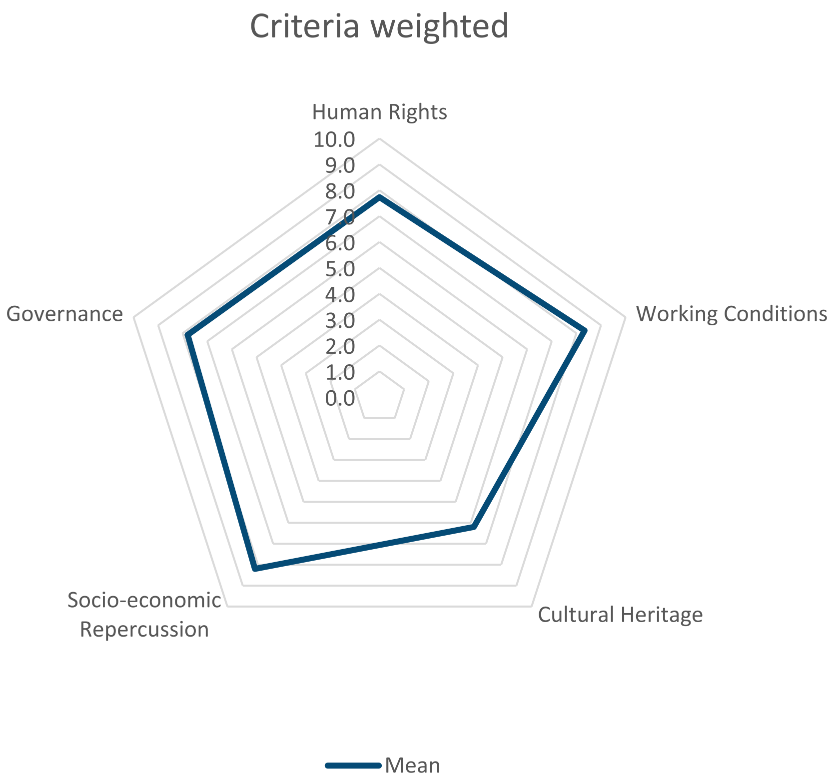

FIGURE 5
Mean social group criteria weighted.

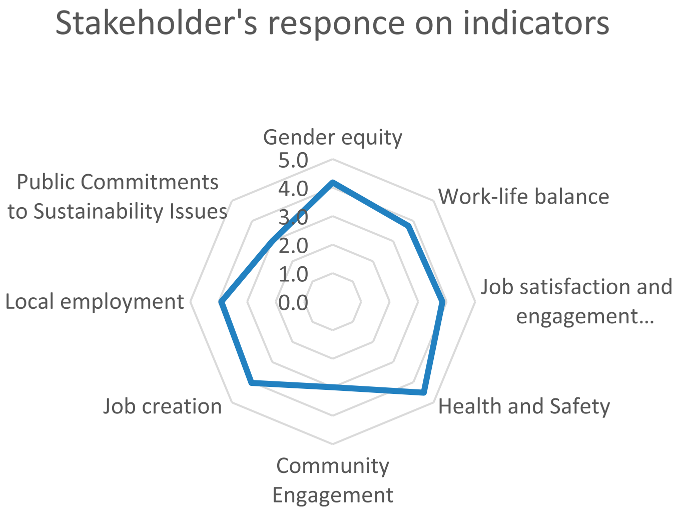

FIGURE 6
Social criteria weighted.

decision-making processes. Lastly, the Governance group incorporated Public Commitments to address sustainability issues.

The conducted social cost-benefit analysis, assessed the project's viability from a public perspective, not just from the viewpoint of shareholders. This analysis identified and quantified the project's economic and social costs and benefits, mainly regarding greenhouse gas emissions. However, the analysis also factored in social costs, which included the initial investment and operational expenses. The main findings, which are in line with existing literature, underscored a significant gain in Social Cost-Benefit, particularly in terms of reduced greenhouse gas emissions which were examined in more detail.

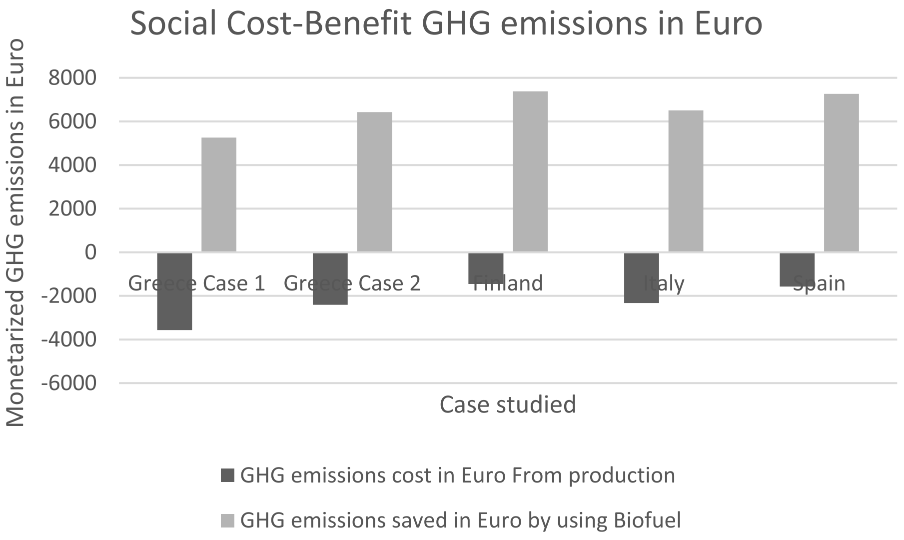

FIGURE 7
The "greenhouse gas emissions".

The BioSFerA Project's findings contribute to the broader discourse on sustainable and socially responsible of biofuel production. These insights can guide decision-makers in balancing the economic, environmental, and social aspects of biofuel development. This study demonstrates how combined analysis S-LCA and S-LCCA provides a holistic perspective on the potential social impacts of introducing biofuel, allowing decision-makers to make informed choices that take into account both the benefits and costs for the affected community.

In conclusion, the BioSFerA Project underscores the complexity of biofuel production and the need for a balanced approach that considers the diverse impacts on society. This project serves as a stepping stone towards a more sustainable and socially responsible biofuel industry.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participant's legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

EK: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. DL: Supervision, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The authors kindly acknowledge the financial support of the European project "BioSFerA" (https://biosfera-project.eu, accessed on 26 March 2024), funded by the European Union's Horizon 2020 research and innovation programme (Grant Agreement 884208).

Acknowledgments

The authors kindly acknowledge the financial support of the European project "BioSFerA" funded by the European Union's Horizon 2020 Research and Innovation Programme (Grant Agreement 884208) for a part of the current research work. They also thank the project partners for their cooperation and help.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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