ASSESSING AND PRIORITIZING CHALLENGES FACING BIOENERGY SUPPLY CHAIN IN NORWAY: A DELPHI-AHP METHOD

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ABSTRACT
Norway is leading the share of renewable energy in Europe by almost 75%. However, the share of bioenergy in Norway's energy supply is insignificant. Bioenergy, the most common type of renewable energy, generates more energy than all other forms. This fact demonstrates the value of bioenergy, which will play an increasingly important part in the future energy mix. There are different biomass resources such as agricultural crop residues, forestry, wood processing residues, algae, dedicated energy crops, and municipal and wet organic waste. Biofuel markets in Norway are relatively immature. In past decades, bioenergy consumption in Norway ranged between 4% and 6% of the total primary energy supply. Norway has experienced a gradual increase in total energy supply of biofuels and wastes, and it has almost doubled since 1990, which is 80 petajoule in 2020. However, various barriers are hindering the development of the biomass industry. The present study aims to identify and classify Norway's biomass supply chain challenges and prioritize them using the Delphi-Analytic Hierarchy Process (AHP) method. Based on a comprehensive literature review, 42 challenges were recognized and classified into seven major categories. Then, a Delphi technique is used to define and choose the main challenges in the context of Norway through an expert panel. Finally, 4 main categories, 9 sub-categories, and 37 challenge indicators related to Norway's biomass industry were selected. Moreover, the AHP method is employed to determine the weight of the challenges using a geometric mean approach. The results show that 'high investment cost', 'Greenhouse Gas (GHG) emission', 'minor differences between the energy prices achievable for the sales of heat and electricity', and 'small market size' were the most critical challenge indicators.
Keywords: AHP, barriers, biomass, bioenergy supply chain, Delphi.

1 INTRODUCTION

The use of fossil fuels is a significant driver of economic growth, but it also causes serious challenges such as negative environmental impacts and energy security [1]. Therefore, to fulfill energy needs without polluting the environment, demand for alternative renewable energies is growing [2], where bioenergy is seen as a viable alternative with great potential [1]. Biomass resources, which provide 14% of the world's energy (equivalent to 25 million oil barrels per day), can be the world's most significant and sustainable energy source [1], [3]. Biomass is as old as human civilization and meets day-to-day energy needs [4]. Biomass now accounts for 46% of all renewable energy and 4.6% of total national energy consumption in the United States [5]. For 2030, the European Parliament and the European Union (EU) council have set ambitious renewable energy targets. According to EU directive vol 328 [6], the union's minimum share of renewable energy consumption should be 32% by 2030. The Nordic countries have shown a good record in bioenergy production, and other EU members can benefit from their experience with bioenergy production and forestry technology [7]. In Europe, Norway's highest share of electricity is produced from renewable sources, primarily hydropower, with 81% in 2018. In the same year, Norway's share of renewable energy was the highest (73%) compared to other Nordic countries such as Sweden, Finland, and Denmark (55%, 41%, and 36%, respectively). In Norway, however, bioenergy contributes about 6% of the total renewable energy, mainly for transportation and heating purposes [8].

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Biomass can be categorized as primary biomass harvested directly for energy or secondary biomass (residues and waste) [9]. In another classification, biomass can be categorized as land-based and aquatic biomass [10]. The land-based biomass includes forestry, waste, and agricultural resources, while aquatic biomasses include microalgae and seaweed. The most commonly used types of biomass sources worldwide [7, 11, 12] are shown in Fig. 1. In Norway, forestry biomass has the most potential for bioenergy dissemination [8], followed by waste used in district heating [7]. In Norway, biomass availability is not considered a constraint to the growing use of bioenergy. However, in the medium term, a rise in biomass supply would necessitate higher pricing to incentivize producers to supply biomass [8]. Biomass availability leads to the cost of purchasing biomass being a significant challenge compared to other energy sources. Norway's forests occupy roughly 122,000 square kilometers, or 38% of the country's land area. Around 86,600 square kilometers of this are productive forests, which generate enough timber to be used as an energy source. Norway now boasts about 11 billion trees with a diameter of 5 cm or more [13]. Norway's most crucial biomass resources include firewood, wood chips, logging residues, thinning residues, and clear-cut stumps [7]. Due to environmental or economic considerations, at the moment, these resources are being utilized to a limited extent [7, 14]. Agricultural biomass plays a minor role in the Nordic energy supply despite the extensive experience, research and development efforts, and economic incentives [14]. Agricultural land occupies roughly one million hectares, or 3% of Norway's total land area, with grasslands and meadows accounting for 64%, cereals and oilseeds for 31%, and organic farming for 4% [7]. In Norway, there is no commercial production of crops for energy. The potential yields of several oilseed crops were investigated in different parts of Norway as part of a Norwegian project on biodiesel production from crops [15]. Enormous potentials are also associated with aquatic biomass, such as macroalgae, along the Norwegian coast. Combinations of the current aquaculture industry and the emerging marine biomass-based industry, such as aquaculture built alongside and on the grounds of the old fishing industry, are also possible. Norway harvested 154,150 tons of macroalgae with 30 million NOK in 2013. However, the macroalgae production potential has been estimated to be 20 million tons by 2050 [16].

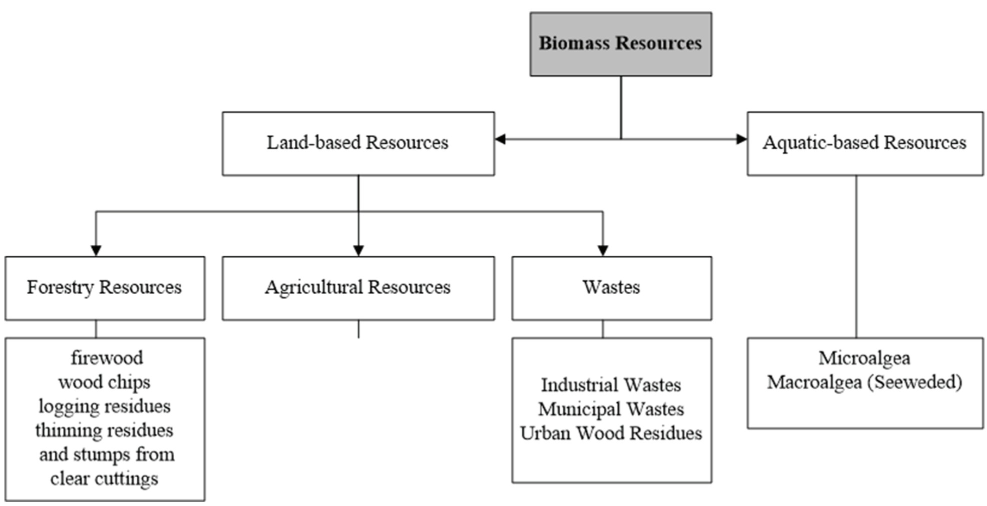

Figure 1: Biomass resources categories.

Yadav and Yadav [17] defined the biomass supply chain (BSC) as 'the association of material between the initial source and the end-user'. Different activities are involved in the BSC process: farming, harvesting, preparing, shipping, handling, and storage. Some of the actions in this procedure suffer from some limitations. For example, harvesting is usually done for a limited period in locations dedicated to biomass production by machines, and in most cases, this procedure will result in a 10–20% loss of biomass [12]. BSC comprises four business entities: a raw material supplier, a manufacturer, a distribution center, and a consumer [18]. BSC management focuses on integrating all of these entities so that the end product is fabricated and distributed in the correct quantity, at the right time, to the right location, with the best possible quality and service at the lowest possible cost [19]. A complex BSC involves two interdependent (production and control) processes and interconnected processes (distribution and logistical) [17]. Planting, harvesting, baling, and pre-treatment of biomass are included in the interdependent processes, whereas storage and transportation are primarily included in the interconnected processes [20]. Furthermore, BSC deals with biomass supply and its possible uncertainties to assess the industry's commercial viability [17].

Norway's biofuel market is still in its development. In the past few decades, Norwegian bioenergy consumption fluctuated between 4% and 6% of total primary energy consumption (TPES) [21]. From 2010 to 2014, solid biomass consumption declined from over 50 to 35 petajoules (PJ). It was primarily due to closures in the pulp and paper industry and a reduction in the use of firewood for heating in the private sector. Norway's total energy supply of biofuels and wastes has steadily increased since 1990, nearly doubling to 80 PJ, which was almost 6.4% of TPES in 2020 [22]. Before, the low overall electricity price and poorly developed infrastructure for central heating systems have been cited as the most significant barriers to bioenergy development in Norway. However, these factors have shifted to the point where they are no longer a barrier [23]. Hence, the present study uses the experts' opinions to study and assess the current challenges associated with Norway's BSC. The Delphi technique and the Analytic Hierarchy Process (AHP) methodology have been employed to rank the barriers. The remainder of the article is organized as follows: Section 2 gives a brief literature review of addressed barriers and challenges associated with the BSC; Section 3 provides the research methodology; Section 4 results and discusses the results based on the research questions; Section 5 concludes the study.

2 LITERATURE REVIEW

This section provides a brief literature review addressing barriers and challenges associated with the BSC (Fig. 2) in different countries to pursue the research goals. Irfan *et al.* [24] systematically prioritized the Indian biomass industry's barriers based on their importance. Through a literature study and a modified Delphi technique, they identified 24 barriers and categorized them into five broad groups. Moreover, they employed AHP to identify the significant barriers' ranks and sub-barriers based on weight allocations. Their results showed that the top-ranked barrier was 'technological-infrastructural', followed by 'economic-financial', 'political and institutional', 'cultural-behavioral', and 'meteorological'. Overall, 'technical complexity' was ranked first among all sub-barriers in all categories. The best alternative solution has been proposed as 'enhancing research and development activities'. Tseng *et al.* [25] contributed to understanding renewable energy sources in Indonesia by identifying factors that act as barriers and facilitators to adopting renewable energy sources in the presence of uncertainty. As a result, based on qualitative data and linguistic preferences, this study used the fuzzy-Delphi method to identify a legitimate set of barriers to

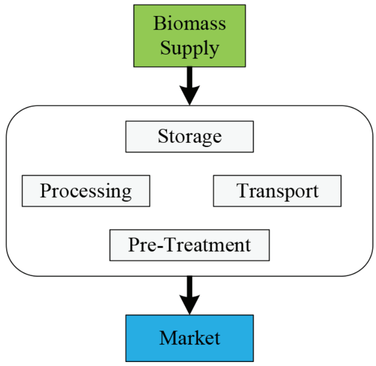

Figure 2: Overall BSC.

adopting renewable energy sources. Furthermore, it employed a fuzzy decision-making trial to picture the interrelationships among qualitatively valid attributes under uncertainty. Results indicated that technical capabilities drive adoption, with technical analysis acting as a primary barrier.

Ma *et al.* [1] developed an Intuitionistic Fuzzy Cognitive Map (IFCM) based on expert opinions and existing literature to evaluate how to improve the public acceptability of biomass production in China. The result showed that the components related to the government, such as policy and regulation, financial support, and promotion information, had a significant effect on the other indicators. On the other hand, the most significant indicators were 'availability of technology' and the 'maturity of the technology'. As a result, it was stated that biomass technology development is more cost-sensitive in China.

From a Nepalese viewpoint, Ghimire and Kim [26] aimed to identify and evaluate the barriers to developing renewable energy and using previous research, project technical reports, policy documents, and site visits resulted in identifying 22 main barriers, which were categorized in the economic, social, technical, policy and political, administrative, and geographical groups. For evaluating and rating the barriers, an AHP technique was employed. According to the results, the two most significant barriers were economic and 'policy and political' barriers. Combining qualitative and quantitative approaches, Mukeshimana *et al.* [2] aimed to identify and assess the primary barriers to disseminating the biogas industry in Rwanda. Barriers were discovered after a thorough literature review and were divided into four categories: financial, technical, socio-cultural, and institutional. A group of specialists participating in Rwanda's biogas program chose the top 20 most considerable barriers. The importance of the barriers was then ranked using the AHP. The results revealed that financial barriers were the most significant ones. High capital costs and a lack of financial mechanisms were ranked first and second among all barriers in the financial category.

Solangi *et al.* [27] highlighted the seven renewable energy barriers as the main categories and 29 sub-barriers as the indicators that hinder Pakistan from developing renewable energy technologies. Besides, this research provided several ways to overcome these barriers. Using the AHP technique, renewable energy barriers and sub-barriers were assessed and prioritized. The results revealed that economic and financial, political and policy, and market were ranked as Pakistan's most severe barriers to deploying renewable energy technologies. Moreover, the Fuzzy TOPSIS method results indicated that capital subsidies, feed-in tariffs, and policies were the most practical and feasible strategies to overcome these barriers. Numata *et al.* [28] analyzed the barriers associated with renewable-based mini-grid deployment. They prioritized the barriers using AHP, and Rupf *et al.* [29] investigated what has impeded the widespread adoption of biogas technology in Sub-Saharan Africa by examining the primary barriers in different regions. Forbord *et al.* [23] investigated the causes behind the rapid growth of new bioenergy companies in Norway. However, their studies indicated that the industry has challenges in terms of profitability. Using a comparative case method, they approached the subject from the supply chain perspective. Five local and regional forest-based (wood chips) heat supply cases were investigated in three regions. National financial assistance was vital for releasing critical investments at different levels in the chains. Local political engagement was critical for forming the chains, influencing ideas, and techno-economic adaptations. Therefore, economies of scope, local political engagement, and national instruments for financial support were the most critical challenges in this development.

Cavicchi [30] studied the bioenergy development case in Norway from a social, economic, and environmental perspective. They investigated the causal mechanisms of bioenergy development to see what was threatening its Triple Bottom Line sustainability by employing qualitative system dynamics and interviews with local players. For example, the government's move to intervene and assist bighead production had unanticipated consequences, worsening some of the current forestry issues. Therefore, the consequences challenged the local benefits, forestry biomass harvest, long-term economic feasibility, and environmental sustainability of bioenergy production. Results showed that bioenergy development's most significant challenges were conflicting local interests, power relations, and market dynamics. Yu *et al.* [31] proposed a generic model for analyzing biomass production's value chain. In addition, a feasibility assessment for developing a bioenergy plant in northern Norway was presented to evaluate the benefits and challenges of bioenergy production. The primary reported challenges were increase in biomass transportation costs, increase in CO_2 emission from the transportation of biomass, increase in required investment in cold climates, uncertain market demands, and cost and CO_2 emission related to the distribution of biofuels and bio-residue to the potential market. Table 1 highlights the important information from the studies discussed above and summarizes the size of the expert's panel and the most critical criteria obtained from different multi-criteria decision-making methods.

Biofuel is an important part of Norway's energy market, and the country has significant ambitions to increase its share. For example, by 2021, Norway will require 24.5% of traded fuels to be biofuels, and 9% will have to be advanced biofuels. Advanced biofuel sales are considered double those of 'standard' biofuels, thus requiring 4.5% of fuels to be advanced biofuels. Furthermore, the Norwegian government has determined that by 2020, advanced biofuels must constitute 0.5% of all aviation fuels. As discussed earlier, Norway is no longer faced with any barriers to biofuel development, and all that is left are challenges. Very few

Table 1: The summary of the size of the experts' panel and the most significant criteria.

Ref.	No. of experts	Top-ranked barrier	2nd Top-ranked barrier
[1]	8	Policy and regulation	Financial support
[2]	117	Financial	Technical
[24]	13	Technological and infrastructural	Economic and financial
[25]	15	Environmental impact	Innovation capabilities
[26]	81	Economic	Policy and political
[27]	10	Economic and financial	Policy and political

studies have addressed the barriers and challenges facing the bioenergy supply chain in Norway, and as the knowledge gap, the present study aims to find and prioritize the most significant challenges using experts' opinions.

3 RESEARCH METHODOLOGY

The present study aims to address research questions like the following: (i) What are the most crucial bioenergy development challenges in developed countries like Norway? (ii) How might these challenges be prioritized to benefit practitioners and policy-makers? Two different tools at different levels have been employed to address these questions. The first level comprises identifying challenges through a literature review and a modified Delphi method, decisional debate with an expert panel. Experts with relevant backgrounds and expertise were selected from both industry and academia. In the second level, a quantitative approach was employed to evaluate challenges' weights to rank them. The AHP, a popular Multi-Criteria Decision making (MCDM) technique, was used to assess the indicator's weights and the significance of decision makers' judgments in complex decision-making problems [32]. The same expert panel was used, and their opinions were aggregated via AHP. As seen in Appendix 2, the panel involves eight experts. Three experts participated from academia, two Ph.D. with a background in biomass gasification and bioenergy production through electrochemistry and anaerobic digestion, and one researcher with a master's degree with a related background in the circular economy. Moreover, five experts were selected from the industry with related backgrounds in bioenergy investment projects, biofuel production, and renewable energy companies who have first-hand experience in developing and implementing sustainable projects. Figure 3 provides the research procedure and methodology.

3.1 Delphi method

Biomass energy barriers were finalized and classified using the Delphi technique. This method systematically collects experts' opinions through interviews and questionnaires. The experts were selected from the relevant area of interest (industry and academia) and shared their ideas and opinions [33]. There were five basic phases to this procedure: (i) experts

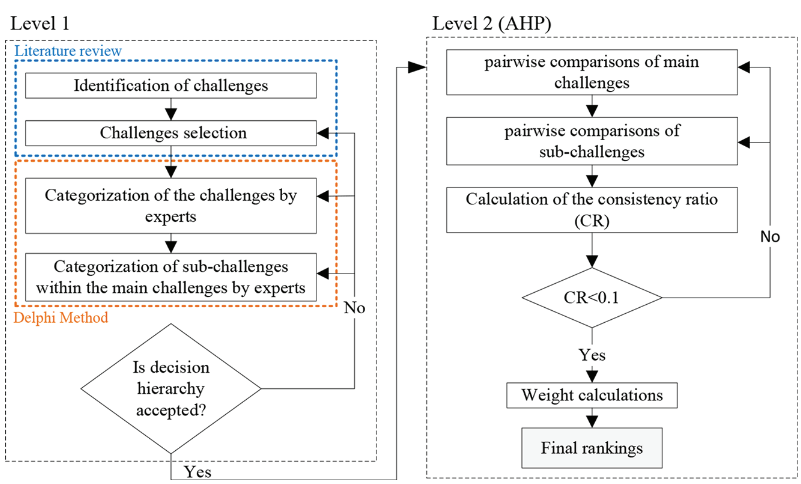

Figure 3: Research procedure and methodology.

selection, (ii) first-round survey, (iii) second-round survey, (iv) integrating expert opinions, and (v) repeat phases (ii) and (iii) until all of the experts concur [24].

3.2 Analytic hierarchy process

The AHP method divides the decision-making process into four steps [34]: Step 1 develops the decision problem's hierarchical pattern, step 2 collects experts' opinions by applying the AHP fundamental scale (see Table 2), and experts assign numbers.

Then, a pair-wise comparison matrix is prepared with a 1–9 point scale for decisions, and step 3 calculates the Consistency Index (CI). During the third phase, the pair-wise comparison matrix's consistency is computed using CI as below:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

where λ_{max} is the eigenvalue, and n denotes the number of major criteria, and the fourth step includes calculating the consistency ratio (CR) [35].

$$CR = \frac{CI}{RI} \tag{2}$$

where RI is the Random Index obtained from Table 3. One critical condition to consider during the pair-wise comparison is that the CR should be less than 0.1. Otherwise, the result would be inconsistent and not trustable. After completing all steps, the AHP technique calculates the primary criteria and sub-criteria weights [32].

Table 2: The fundamental AHP scale (intensity of importance in variables).

Numeric	Linguistic
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between scale values

Table 3: Random Index *(RI)*.

n	*RI*	*n*	*RI*	*n*	*RI*
1	0.00*	4	0.90	7	1.32
2	0.00*	5	1.12	8	1.41
3	0.058	6	1.24	9	1.45
10	1.49	11	1.51	12	1.54
13	1.56	14	1.57	15	1.58

* The $RI = 0$ means this method needs three or more indicators to be weighted.

4 RESULTS AND DISCUSSION

Following the research procedure and methodology given in Fig. 3, this section provides the results obtained from each stage and discusses them.

4.1 Results on the level one

4.1.1 Literature review

As reviewed in Section 2, an initial list of relevant barriers was prepared from the different categories and sub-categories listed in the literature (see Appendix 1). The 42 barriers were categorized into seven different categories. As discussed earlier, most of these are no longer barriers in developed countries. Therefore, in this study, they are known as challenges and not barriers. Appendix 1 will be used in the first round of interviews in the Delphi method.

4.1.2 Final challenges categorization (Delphi)

As discussed earlier, the mentioned barriers in the literature should be adjusted in the context of Norway. The main challenge categories and challenges were chosen below based on the experts' opinions and the Delphi technique. Eight experts with different backgrounds participated in the interviews. Appendix 2 gives an overview of the expert's profile. After two rounds of interviews, the final list of challenge categories and sub-categories has been finalized. Due to being negligible compared to others, some challenges were eliminated, and some other missed challenges were added to the list.

Moreover, the categorization was also optimized for better results in the AHP model. All challenges were categorized into four main categories, namely 'economic and financial', 'technical and technological', 'political and ecological', and 'life cycle challenges'. Each main categories have two or three sub-categories, such as 'low rate of return', 'low credits and intensives', and 'market challenges', which are associated with economic and financial challenges. The hierarchical structure of BSC challenges is illustrated in Fig. 4. Overall, as the challenges in Norway, 37 indicators were categorized into nine sub-categories and four main categories.

4.2 Results on the level two

4.2.1 AHP for main categories

In this section, the results of the challenge categories have been calculated using the AHP approach using a geometric mean approach recommended by literature [36]. Table 4 shows the pair-wise comparison matrix of the main categories. The letters A-D represent the main criteria shown in Fig. 4.

Table 4: The pair-wise comparison matrix and the main categories ranking.

	A	B	C	D	Weight	Rank
A	1	5	7	3	0.56	1st
B	0.2	1	3	0.33	0.12	3rd
C	0.14	0.33	1	0.2	0.05	4th
D	0.33	3	6	1	0.27	2nd

Figure 4: The hierarchical structure of BSC challenges in Norway is based on experts' opinions (Delphi method results).

The results indicate that 'economic and financial challenges' lead by 56%, followed by 'life cycle challenges' by 27%. Experts believe that the weight of these two categories should be about 83% of all challenges. 'Technical and technological challenges' stood third with 12%, and 'political and ecological challenges' got the lowest interest at 5%.

4.2.2 AHP for sub-categories

In the second stage, the pair-wise comparison matrix was calculated for each group of sub-categories. For example, the weights of the three sub-categories in the 'economic and financial' category were calculated (Table 5). The main sub-challenge was 'low rate of return' by 58%, followed by 'market challenges' and 'credits and incentives' by 31% and 11%, respectively.

Similarly, the weight of other sub-categories was calculated (Table 6). Other categories had two sub-categories each. In the 'technical and technological', 'biomass challenges' was the main challenge with 60%, and 'technology and design' stood second place. In the 'political and ecological' category, 'political, policy, and regulatory challenges' were led by 63% in comparison with 'ecological and geographical challenges'. Finally, 'environmental impacts' and 'social impacts' were the sub-categories of 'life cycle challenges' by 72% and 28%, respectively. Figure 5 shows the weight of each sub-category. As seen, the 'low rate of

Table 5: Pair-wise comparison matrix and the sub-categories' ranking for 'economic and financial'.

	A.1	A.2	A.3	Weight	Rank
A.1	1	5	2	0.58	1st
A.2	0.2	1	0.33	0.11	3rd
A.3	0.5	3	1	0.31	2nd

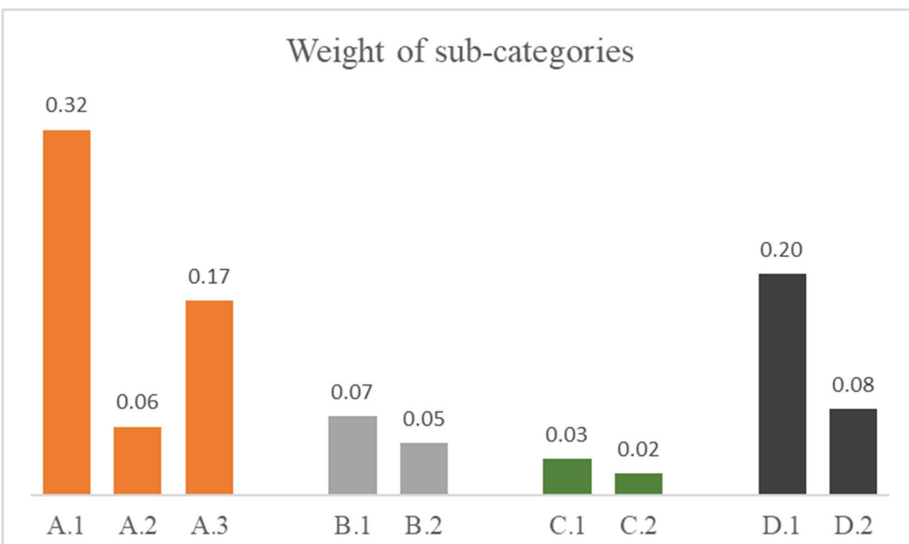

Figure 5: Comparative illustration of sub-category weights (A1-3, B1-2, C1-2, and D1-2 are the sub-categories of four categories listed in Fig. 4).

return', 'environmental impacts', and 'market challenges' are the most significant challenges based on experts' opinions.

4.2.3 AHP for the challenge indicators

Similarly, the AHP method can be applied to challenge indicators for each sub-category in the last stage. For example, a calculated pair-wise comparison matrix is given in Table 7. This table shows the final ranking of the challenge indicators of 'rate of return' that obstruct the growth of the bioenergy industry the most in Norway. As seen, 'high investment cost' and financial' and 'minor differences between the energy prices achievable for the sales of heat and electricity' are the main causes of the low rate of return. In contrast, experts believe that 'high harvesting operations costs' and 'high feedstock acquisition cost' have negligible effect on biomass plants rate of return. Figure 6 and Table 8 provide a graphical and numerical presentation of all categories, sub-categories, and challenge indicators' weights. The calculated weights are given in Table 8.

The concept of sustainable development refers to an approach to development that is economically and socially beneficial, as well as having a minimal impact on the environment. The three criteria listed above and the technological challenges are the most significant factors determining a project's success. In this regard, bioenergy projects are similar to other projects in that they must be evaluated concerning their positive and negative impacts on the economy, society, and the environment.

Economic impacts: Evaluating the projected costs and revenues is always the first step in any project. The cost-effectiveness of bioenergy projects should always be considered com-

Table 6: The pair-wise comparison matrix and the main sub-categories ranking for other categories.

	Weight	Rank
B.1	0.60	1st
B.2	0.40	2nd
C.1	0.63	1st
C.2	0.37	2nd
D.1	0.72	1st
D.2	0.28	2nd

Table 7: The pair-wise comparison matrix and the challenge indicator ranking for 'low rate of return'.

	A.1.1	A.1.2	A.1.3	A.1.4	A.1.5	A.1.6	Weight
A.1.1	1	5	9	5	4	2	0.39
A.1.2	0.2	1	5	3	1	0.3	0.11
A.1.3	0.1	0.2	1	0.2	0.2	0.1	0.02
A.1.4	0.2	0.3	6	1	0.3	0.1	0.06
A.1.5	0.3	1	5	3	1	0.2	0.11
A.1.6	0.5	3	7	7	5	1	0.30

pared to other conventional energy sources. The BSC consists of several key process steps, including collection or harvesting of biomass, storage, pre-processing (densification through compaction, pelleting, etc.), transportation (from the field to the biorefinery), and post-processing at the biorefinery [37]. Feedstock delivery costs will be directly impacted by these steps in the supply chain [38]. Biofuel production is significantly influenced by the cost of feedstocks [39]. On the other hand, biomass harvesting requires a great deal of energy, large machines, and considerable amounts of fuel for transportation [40]. Approximately one-third of the cost of biofuel production is attributed to biomass costs, which are influenced by soil fertility, location, and genetics [39]. It has been reported that biomass's low-density results in the material occupying a greater volume and requiring a greater amount of transportation carrier space, affecting transportation costs. Several factors influence transportation costs, including moisture content, distance from the field to the biorefinery, infrastructure and technology available, and modes of transportation. Moreover, biofuel costs are highly dependent on the size of the biorefineries, which will require optimization based on the location and feedstock.

Environmental impacts: Biofuel production is not an entirely clean process. Even though biofuel processes, such as gasification, significantly reduce negative environmental impacts, they considerably impact the environment [41]. In the long term, unsustainable bioenergy practices can lead to deforestation depending on the type of biomass used to generate electricity. The clear-cutting of forest material for biomass energy plants harms the natural environment and disrupts animal and plant habitats. As a result of removing plants and organic materials from the soil, the soil can also be adversely affected by biomass required for composting and fertilizing. It is also necessary to have a good amount of water for growing crops exclusively for bioenergy resources, and an area may become more vulnerable to drought if it is continuously irrigated. Pesticides and fertilizers may also affect the quality of water. Bioenergy can minimize environmental and health impacts by employing more sustainable land-use practices, replanting efforts, and technological innovation.

As a result of the Delphi technique (see Fig. 4), bioenergy supply chain challenges in Norway were categorized into four main criteria: economic and financial, technical and technological, political and ecological, and life cycle thinking. The results from the aggregation of the experts' opinions revealed that 'economic and financial' and 'life cycle thinking' criteria were the most significant challenges in Norway. As seen in Table 1, economic and financial were among the most critical criteria in almost all studies, the same as the present study. Nevertheless, the experts in this study believed that political and technical challenges were not significant in the context of Norway. Instead, life cycle thinking, including environmental and social impacts, was the second most critical criterion.

The 'economic and financial' category was divided into three sub-categories: low rate of return, market challenges, and credits and incentives. The 'life cycle thinking' challenges were categorized into environmental and social impacts. The analysis of the results at the sub-category level shows that among all nine sub-categories, 'low rate of return' from economic and financial challenges was the top-ranked most critical challenge, followed by 'environmental impacts' from the challenges related to life cycle thinking, and 'market challenges' from economic and financial category.

At the level of the indicators, there are four indicators under the 'environmental impacts' sub-category: deforestation, GHG emissions, the health of the soil, and habits of plants and animals. Among these indicators, GHG emissions and deforestation were selected as the most critical indicators by the expert panel. In his article, Ranum [42] from Rainforest Foundation Norway reported that 'Norway is stifling the use of palm oil-based biofuels and other fuels with a high deforestation risk. This is a victory for the rainforests and the climate'. With the implementation of the new biofuel policy in January 2021, the maximum volume of crop-based biofuel used for blending will be reduced from the current 10.1% to 6.5%. Consequently, deforestation is also among the major policy challenges for Norwegian policy-makers, which has a negative impact on the development of biofuel markets. A resolution adopted by the Norwegian Parliament (Resolution 86) voted to exclude biofuels made from feedstocks with high deforestation risks, such as palm oil, as of January 1, 2020, making Norway the first country to take such measures.

In all Nordic countries, heating and cooling systems have been developed based on local requirements. As a result, Norway, with its abundant hydropower resources, uses a high percentage of electricity for heating, while Iceland uses geothermal energy for heating. Biomass from forests is used in Finland and Sweden, and gas is also used in Denmark. All Nordic countries except Norway rely heavily on district heating. Despite this, the district heating market has grown rapidly in Norway due to the development of new waste-to-energy facilities. In Nordic countries, district heat connections, disconnection rights, and district heat pricing reflect open and liberal heat markets. There are no heat price regulations in Finland or Sweden, and there is no obligation to connect or disconnect. There may be a requirement for the connection in Denmark and Iceland, and disconnection is not always permitted. There are some cases in Norway in which prices must be regulated, while in others, there is no such obligation. Norway has a very small district heating market compared to other Nordic countries due to the availability of relatively cheap electricity and alternative heat sources. Due to the rapid increase in electricity prices in the late 1990s, district heating regulations and investment subsidies were introduced to encourage the construction of district heating systems. Since the early 2000s, investment in district heating and infrastructure capacity has grown significantly. The district heating facilities are mainly located in city areas. Future expansion of district heating capacity may also be possible in new areas such as small cities. In Norway, the government or municipalities own most district heating companies, mostly due to the low rate of returns. Moreover, several initiatives are underway to develop strong business models for solar district heating in Norway, with support from the Norwegian Research Council (NRC). This confirms that there are serious challenges regarding using biofuels in comparison with other renewable sources of energy.

Although AHP is one of the most popular decision-making methodologies, it is not without limitations and suffers from uncertainty. Toth and Vacik [43] comprehensively analyzed the uncertainty issues associated with the AHP. They listed some questions to brighten the uncertainties and their sources in their study. The questions were as follows: How is an appropriate group aggregation derived from combining the judgments of several decision-makers (e.g. geometric mean on pair-wise comparisons, weighted arithmetic mean on priority determination or consensus models)? What type of sensitivity analysis could be conducted? (e.g. variation in judgments or one-dimensional/multidimensional simulation approaches)? At what level of the problem modelling hierarchy should preferences be aggregated (additive or multiplicative)? If pair-wise comparison matrices are used to derive preference values, how should those values be calculated (e.g. synthesis mode, normalization procedure, rank preservation, and reversal issues)? Does the eigenvalue method provide sufficient information to determine priority? How can one ensure (e.g. by using random indices?) that the decision makers' judgments are logical, reasonable, and non-random? How to deal with incomplete pair-wise comparison matrices (e.g. Monte Carlo simulation approaches or optimization methods)? What methods (e.g. interval judgments or fuzzy set theory) can be used to incorporate human judgment's imprecision? How should important but 'unknown' factors be incorporated into the problem modeling process? Moreover, how do the number of decision-makers and their areas and level of proficiencies affect the results?

The pair-wise comparisons in real applications are subject to judgmental errors. They are inconsistent since decision-makers do not have complete information regarding all aspects of the decision-making process or a proper understanding of a decision problem. As a result, there is a degree of uncertainty associated with the weight point estimates provided by the eigenvector method or any other method, including least squares, weighted least squares, logarithmic least squares, and robust regression [44, 45]. There are different approaches to cope with the uncertainty in the AHP method, such as the Monte Carlo simulation [46–51] and the fuzzy set theory approach [52–57].

4.3 Limitations

As discussed above, uncertainty analysis could play a significant role in AHP or even Delphi methods. Thus, this study has not explored the discussed uncertainties as a limitation. Besides analytical uncertainty approaches, it is possible to enhance the results by expanding the expert panel and inviting more experts with expertise in policy and regulation, social sciences, and economics.

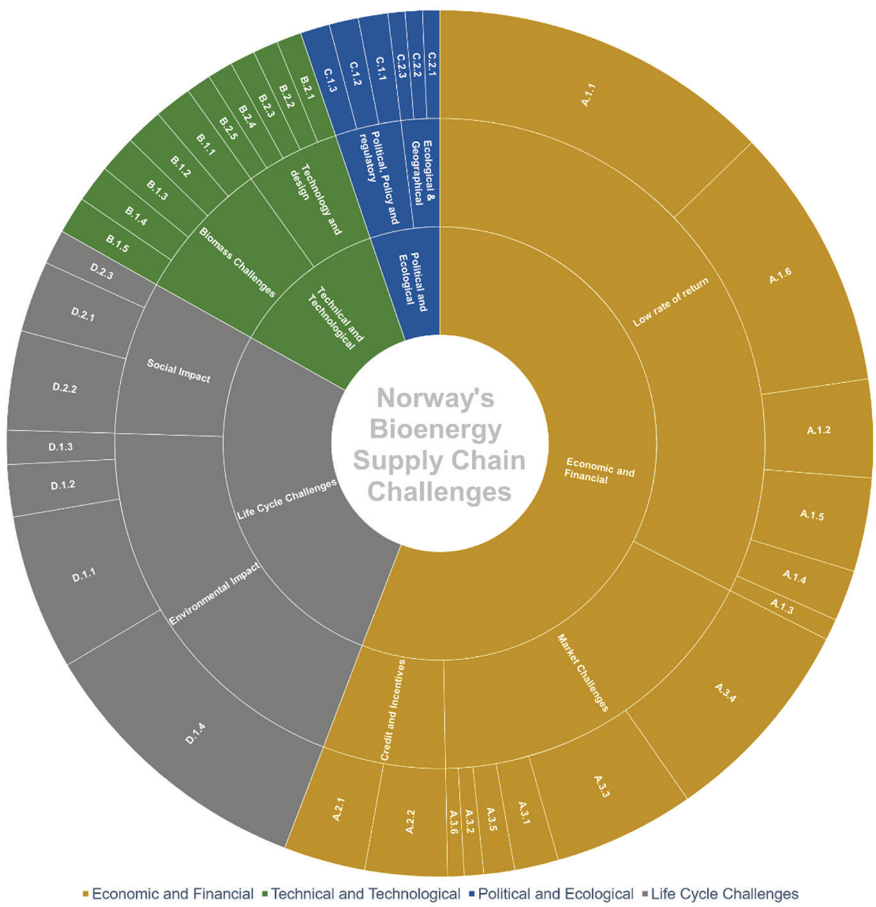

Figure 6: Illustration categories, sub-categories, and challenge indicators' weights.

Table 8: AHP summary of all challenge indicators.

Code	Challenge indicators	Weights in sub-categories	Overall weights (%)
A.1.1	High capital cost	0.39	12.8
A.1.2	High operation and maintenance cost	0.11	3.7
A.1.3	High cost of energy	0.02	0.8
A.1.4	High harvesting operations costs	0.06	1.9
A.1.5	High Feedstock acquisition cost	0.11	3.5
A.1.6	Minor differences between the energy prices	0.30	9.8
A.2.1	Minimum acess to credit for establishing biogas plants	0.50	3.1
A.2.2	Lack of financial incentives	0.50	3.1
A.3.1	Lack of consumer paying capacity	0.10	1.6
A.3.2	Lack of consumer awareness	0.04	0.7
A.3.3	Uncertain market demand	0.31	5.3
A.3.4	Small market size	0.46	7.9
A.3.5	Lack of sufficient market based	0.07	1.1
A.3.6	Tariff structure	0.04	0.6
B.1.1	Inadequate availability of feedstock	0.20	1.4
B.1.2	Biomass efficiency	0.20	1.4
B.1.3	Storage and preserving biomass	0.20	1.4
B.1.4	Biomass pretreatment processes	0.20	1.4
B.1.5	Low Energ density for large scale supply	0.20	1.4
B.2.1	R&D and Technology Adoptation	0.20	0.9
B.2.2	Risks & uncertainties	0.20	0.9
B.2.3	Immature industry chain	0.20	0.9
B.2.4	Biomass plants require a lot of space	0.20	0.9
B.2.5	Imperfect district heating systems (WtE)	0.20	0.9
C.1.1	Political instability	0.33	1.1
C.1.2	Regulatory framework	0.33	1.1
C.1.3	Harvesting restrictions	0.33	1.1
C.2.1	Ecological issues	0.33	0.6
C.2.2	Transportation and distribution related problem	0.33	0.6
C.2.3	Scattered households and electricity distrinution	0.33	0.6
D.1.1	Deforestation	0.30	5.8
D.1.2	Disrupting the habitats of plants and animals	0.10	2.0
D.1.3	Health of soil	0.06	1.3
D.1.4	GHG emissions	0.54	10.6
D.2.1	Land use issues	0.35	2.7
D.2.2	Loss of biodiversity	0.48	3.7
D.2.3	Increase in service and traficc in rural areas	0.17	1.3

5 CONCLUSION

The present study reviews the essential BSC's challenges or barriers and for Norway's sustainable development of the bioenergy industry. To perform this analysis, a Delphi technique was used to define and choose the main challenges in the context of Norway using experts' opinions. Forty-two challenges (mentioned as barriers in the literature) in seven categories were selected for the Delphi technique. These pre-selected challenges were used in two-round interviews (Delphi method) through an expert panel from industry and academia. The output of the Delphi method was a list of relevant challenges that all the experts agreed on. In the last step, an AHP method was employed to determine the weight of the challenges using a geometric mean approach. As a result, the pair-wise comparison matrix of the AHP outcomes has been used in group decision-making. The results showed that among four main categories, 'economic and financial' and 'life cycle' challenges were the most significant challenges, and 'technical and technological' and 'political and ecological' challenges were the categories with the lowest challenge. Among the sub-categories, 'low rate of return', 'environmental impacts', and 'market challenges' were the most significant challenges based on expert's opinion. 'High investment cost', 'GHG emissions', 'minor differences between the energy prices achievable for the sales of heat and electricity', and 'small market size' were the most critical challenge indicators. Although bioenergy, in comparison with fossil fuels, has considerable better performance in terms of environment, these huge amounts of challenges keep the share of these energies low in the market. Quantification of qualitative data suffer from uncertainties. Therefore, it is suggested to apply uncertainty to the model for further studies, such as the fuzzy-AHP technique. In addition, having a panel of experts with a wide range of expertise helps to ensure the model is robust.

Appendix 1: The initial list of barriers/challenges associated with renewable energy and the bioenergy industry from the literature.

1	***Economic and Financial***	3.4	Uncertain market demand
1.1	High capital cost	3.5	Small market size
1.2	High operation and maintenance cost	3.6	Lack of sufficient market based
1.3	Lack of distribution networks	***4***	***Institutional, Administrative***
1.4	Lack of financing mechanism	4.1	Lack of coordination
1.5	Lack of credit access	4.2	Lack of Institutional capacity
1.6	Lack of financial incentives	4.3	Lack of delivery mechanism
1.7	Low rate of return	4.4	Lack of skilled human resources
1.8	Lack of consumer paying capacity	***5***	***Political, Policy, and Regulatory***
1.9	Currency risks	5.1	Political instability
1.10	High cost of energy	5.2	Lack of transparent decision process
1.11	Tariff structure	5.3	Regulatory framework
1.12	Lack of subsidy	5.4	Corruption and Nepotism
2	***Technical***	5.5	Lack of decision-making power
2.1	Lack of R&D	5.6	Lack of coherent RE policy

(*Continued*)

Appendix 1: The initial list of barriers/challenges associated with renewable energy and the bioenergy industry from the literature. (*Cont.*)

2.2	Absence of on-grid accessibility	***6***	***Ecological and Geographical***
2.3	Risk & uncertainty	6.1	Ecological issues
2.4	Inadequate availability of feedstock	6.2	Transportation problem
2.5	Unreliable supply	6.3	Scattered households
2.6	Negative environmental impacts	***7***	***Social and Cultural***
2.7	Lack of infrastructure	7.1	Lack of public interest
2.8	Lack of technology	7.2	Lack of public awareness
3	***Market***	7.3	Lack of public acceptance
3.1	High investment cost		
3.2	Lack of consumer paying capacity		
3.3	Lack of consumer awareness		

Appendix 2: Profiles of experts.

Expert	Years of experience	Position	Education background
1	20	Industry	Master of Science
2	17	Industry	Master of Science
3	9	Industry	Master of Science
4	15	Industry	Master of Science
5	8	Industry	Master of Science
6	4	Academic	PhD
7	6	Academic	PhD
8	13	Academic	Master of Science

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