BioTheRoS

Collaborative actions to bring novel **BIO**fuels **THE**rmochemical **RO**utes into industrial **S**cale

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Executive Summary

This report provides a comprehensive analysis of the current market conditions, stakeholder dynamics, and product performance within the EU and BioTheRoS countries for advanced aviation and shipping fuels. It starts with outlining the purpose, scope and objectives of the study, providing a brief overview of the market landscape. The methodology section details the research methods ana analytical approaches employed to gather and analyze data.

A detailed examination of the market factors, including political, economic, social, technological, environmental and legal aspects is presented for each country as well as the EU. This analysis highlights the potential opportunities and challenges that fuels might face. This report also identifies and evaluates key stakeholders in each market. This offers insights into stakeholder relationships and their impact on market dynamics.

This report offers a comprehensive analysis of their market conditions for successful market penetration for advanced aviation and shipping fuels. While this analysis provides a solid foundation, upcoming iterations of the report in M24 and M36 will delve deeper into interpretations and provide strategic recommendations to further support the deployment and uptake of these innovative fuels in the EU.

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Introduction

The BioTheRoS Project seeks to develop an integrated approach to accelerate sustainable biofuel production through thermochemical conversion technologies. By bringing together key players from Europe and beyond—such as technological and social experts, renewable energy associations, and industrial stakeholders—the project aims to foster international cooperation, which is crucial for scaling and commercializing biofuels. Given the existence of numerous global projects and initiatives, BioTheRoS will collaborate closely with the ETIP Bioenergy and Technology Collaboration Programmes (TCPs) within the International Energy Agency (IEA).

The project's first step is to assess current pre-treatment technologies and the availability of biomass feedstocks. Predictive AI models will be employed to identify globally abundant feedstocks suitable for sustainable pyrolysis and gasification-based biofuel value chains. Pilot experiments will be conducted to validate these value chains. Despite differences between pyrolysis and gasification, BioTheRoS will leverage synergies through a multidisciplinary, stepwise approach involving feedstock selection, experimental validation, and simulation and modeling for scaling up.

The scope of this market analysis methodology will cover the EU level and selected countries: Germany, Austria, Netherlands, Spain and Greece. The report is based on mixed methods approach. Initially, desktop research is used to gather first data required to the analysis. Local conditions and stakeholders for the two focus technologies have been assessed using PESTEL analysis at both national (Germany, Austria, Netherlands, Spain, Greece) and European levels. The first version of the report contains also the preliminary analysis of the relevant stakeholders in the selected markets. Besides, an initial detailed analysis of the processes and products has been conducted, to better understand each process/product and strategize their market uptake and positioning.

This report will be updated at M24 and M36.

Methodology of the Study

The geographical scope of the analysis covers representatives of three different European regions (Central, West, East), including countries where the project's demonstrations take place: Austria and Netherlands.

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The analysis particularly focuses on the topics presented on the Figure 1. The products covered are the pyrolysis products and gasification products.

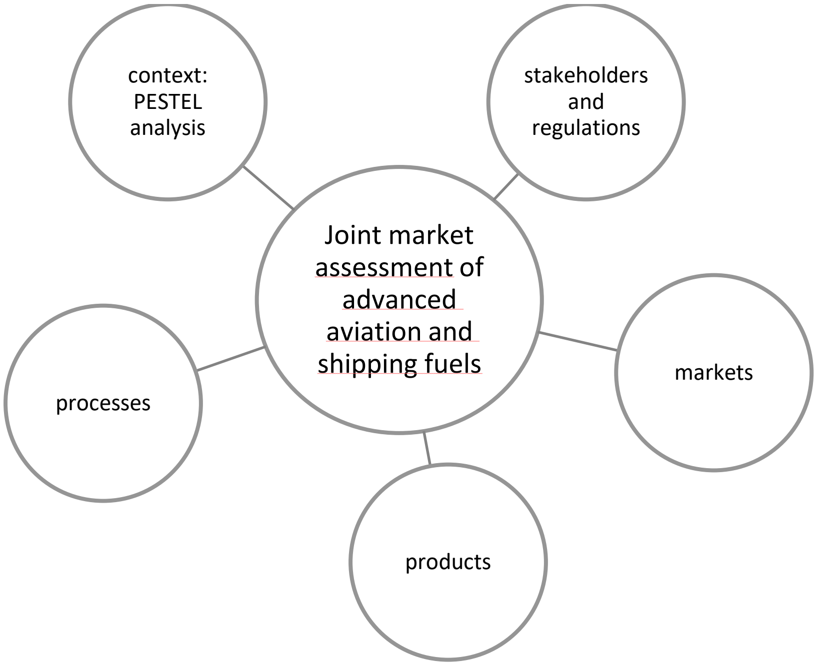

Figure 1: Topics covered in the market assessment

In the first step, to investigate the context of the market activity, the PESTEL analysis was conducted using secondary data sources. PESTEL stands for political, economic, social, technological, environmental and legal factors in the external environment that influence the studied phenomenon, in this case markets for the BioTheRoS focus processes and products. Relevant data was gathered from the desktop research. Similar procedure is followed in the case of stakeholders' identification. Stakeholders has been described as target groups in D8.1 Dissemination and Communication Plan, in this D8.13, national players for each target group will be listed.

PESTEL Analysis

All partners conduct a PESTEL analysis to understand the opportunities and challenges associated with the integration of advanced aviation and shipping fuels. This holistic approach ensures that all relevant factors are considered, enabling a nuanced evaluation of the market landscape and the strategic pathways for promoting advanced fuels in these diverse European contexts. WIP will conduct PESTEL for Germany, Austria and Netherlands; CERTH will conduct PESTEL for Greece and Spain.

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This chapter delves into a comprehensive analysis of the advanced aviation and shipping fuels market in five diverse European countries, being the project's countries: Netherlands, Germany, Austria, Spain and Greece. To fully understand the regional characteristics and viability of advanced fuels in these nations, a detailed PESTEL analysis has been conducted, including political, economic, social, technological, environmental, and legal conditions.

- **Political conditions:**

  An examination of the laws, rules, and political climate that affect the creation and use of advanced fuels. This covers guidelines, incentives, and subsidies at the national and EU levels.

- **Economic conditions:**

  Analysis of economic variables such market size, potential for growth, and stability of the economy. It also considers cost competitiveness, the financial sustainability of advanced fuels, and the influence of economic cycles on fuel demand.

- **Social conditions:**

  Assessment of public understanding, societal attitudes, and acceptability of advanced fuels. This covers consumer behavior, cultural aspects, demographics and other relevant statistics.

- **Technological conditions:**

  Evaluation of technical developments and inventions in the production, distribution, and use of fuels. This section looks at each nation's unique R&D efforts, infrastructure availability, and technological capabilities.

- **Environmental conditions:**

  Examination of environmental factors, such as national environmental regulations, sustainability objectives, and the environmental effects of fuel consumption. Additionally, it assesses how advanced fuels fit into environmental goals and efforts to mitigate climate change.

- **Legal conditions:**

  Examination of the applicable laws, rules, and compliance specifications as well as the legislative framework controlling advanced fuels. This includes international agreements as well as national laws that have an impact on the shipping and aviation industries.

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Germany	
Political	• Climate Action Act (Klimaschutzgesetz) sets legally binding national climate targets for Germany, aiming for greenhouse gas neutrality by 2045. It includes measures across various sectors to ensure these targets are met [1]. • CO2 Pricing policy involves setting a price on carbon emissions to incentivize reductions. Starting in 2024, the price is set at €45 per ton of CO2, with plans to increase it gradually [1]. • Subsidies for climate-friendly engines: The German government provides financial assistance for purchasing commercial vehicles and buses with climate-friendly engines, as well as for expanding electric vehicle charging infrastructure [2]. • Financial assistance includes various forms of support, such as grants and tax benefits, aimed at promoting climate action and environmental protection. The focus is on making climate-friendly investments more attractive and affordable [2].
Economic	• The advanced fuels market, including biofuels and hydrogen, is growing as part of the country's energy transition strategy [3]. • The biofuels market in Germany accounted for the largest share of over 18.8% in 2023 [4]. • The financial sustainability of advanced fuels in Germany indeed relies significantly on government support. This includes subsidies, tax incentives, and grants for research and development. Germany's robust policy framework, such as the Renewable Energy Sources Act (EEG) and the National Hydrogen Strategy, ensures continuous financial backing for advanced fuel technologies, thereby enhancing their long-term viability [5].
Social	• Germans generally exhibit high awareness of climate change and its impacts, which drives positive public sentiment towards renewable energy and sustainable fuels. • While there is support for advanced biofuels (e.g., second-generation biofuels from waste or non-food biomass), first-generation biofuels, which use food crops, face some public skepticism. Concerns revolve around issues like land use, deforestation, and food security. • Studies indicate that the general acceptance of advanced fuels, such as biofuels and hydrogen, is relatively high in Germany. However, local acceptance can be lower due to concerns about environmental impacts and infrastructure [6]. • German consumers show increasing interest in sustainable transport options, with a growing number purchasing electric vehicles (EVs) or supporting low-carbon alternatives like biofuels and e-fuels. Approximately 18% of new car sales in 2023 were electric, reflecting a shift towards greener energy sources [7].
Technological	• Germany is actively investing in the development of SAF through initiatives like the aireg (Aviation Initiative for Renewable Energy in Germany). This

	includes research on various production pathways such as Hydroprocessed Esters and Fatty Acids (HEFA) and Power-to-Liquid (PtL) technologies [8]. • Germany has several ongoing SAF projects, with significant production capacities expected to come online by 2030. The country is also developing the necessary infrastructure to support large-scale SAF production and distribution [9].
Environmental	• Germany has a temperate seasonal climate, with moderate to heavy rainfall throughout the year. Winters are generally mild, and summers can be warm, especially in the southern regions [10]. • Germany has significant deposits of lignite (brown coal), potash, and rock salt. However, the country is moving away from coal to reduce carbon emissions [10]. • Forests cover about 33% of Germany's land area. The Black Forest, Bavarian Forest, and Harz Mountains are notable forested regions [11]. • Germany has experienced a significant increase in average temperatures over the past decades. This trend is expected to continue, leading to more frequent heatwaves [10].
Legal	• The adoption of advanced fuels in the shipping industry is driven by both national and international regulations aimed at reducing sulfur and greenhouse gas emissions. Germany's ports are increasingly equipped with infrastructure to support the use of cleaner fuels [12]. • The EU and Germany have set a greenhouse gas (GHG) reduction obligation for SAF, starting at 2% in 2023 and increasing to 10% by 2030 [13].

Austria	
Political	• The Renewable Energy Expansion Act (EAG), enacted in 2021, provides a legal framework for promoting renewable energy, including advanced biofuels, through subsidies and incentives [14]. • Nationally, Austria's Climate and Energy Strategy outlines the country's commitment to reducing greenhouse gas emissions and increasing the use of renewable energy sources, including advanced fuels [15].
Economic	• The market size is substantial, particularly in Vienna, which performs economically at around 150% above the EU average [16]. • The potential for growth is moderate, with the economy expected to grow by 0.3% in 2024 and by 1.8% in 2025 [17]. • The financial sustainability of advanced fuels is supported by national and EU-level incentives, such as subsidies under the Renewable Energy Expansion Act and funding from the European Green Deal [18].
Social	• Austria has implemented various measures to increase public awareness and provide training related to energy efficiency and renewable energy. These initiatives are part of the national energy efficiency action plans and aim to promote behavioral change and energy savings [19]. • Efforts are made to encourage consumers to choose sustainable options, including the use of advanced fuels in transportation. Campaigns and incentives are designed to promote environmentally friendly choices [20].

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	• The biofuel sector in Austria also contributes to job creation, although specific numbers for direct and indirect jobs are not readily available. The sector is supported by national and EU-level policies aimed at increasing the use of renewable energy sources [20].
Technological	• Austria's R&D intensity reached 3.26% of GDP in 2022, with significant investments in energy and environmental technologies [21]. • The Austrian Research Promotion Agency (FFG) supports numerous projects focused on advanced fuels and renewable energy [22]. • Austria is a leader in biomass technology, with advanced systems for biomass heating and power generation. • The country is also making strides in the development of synthetic fuels and e-fuels, supported by both national and EU funding.
Environmental	• Advanced fuels are integral to Austria's strategy to reduce greenhouse gas emissions and achieve carbon neutrality [23]. • Austria aims to achieve carbon neutrality by 2040 and has set a target of 46-50% renewable energy by 2030 [23]. • The country focuses on sustainable water management, energy efficiency, sustainable agriculture, and forestry as part of its commitment to the Sustainable Development Goals (SDGs) [24].
Legal	• Renewable Energy Directive (RED II), EU directive mandates that member states, including Austria, achieve a minimum share of renewable energy in their transport sectors, with specific targets for advanced biofuels. • Alternative Fuels Infrastructure Regulation (AFIR) requires Austria (like other Member States) to develop infrastructure for alternative fuels, including electric and hydrogen refueling stations, to support the transition to low-emission mobility [25]. • Austria adheres to IMO regulations, which include measures to reduce greenhouse gas emissions from ships and promote the use of alternative fuels [26]. • Austria complies with ICAO standards, including the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which aims to reduce emissions from international aviation [27].

Netherlands	
Political	• The Dutch government aims to reduce greenhouse gas emissions by 49% by 2030 and 95% by 2050, compared to 1990 levels [28]. • National Climate Agreement: This agreement includes measures and policies to achieve climate goals, focusing on sectors like electricity, industry, and transport [28]. • The Netherlands is committed to phasing out fossil fuel subsidies, as stated in a joint declaration with other countries [29].
Economic	• The Netherlands has a significant market size, being the 17th largest economy in the world and the 5th largest in the EU [30].

	• The economy is expected to grow modestly, with projections of 0.5% growth in 2024 and 1.3% in 2025 [30]. • The Dutch economy is stable, with low inflation rates projected to fall to 2.8% in 2024 and remain around this level in subsequent years [30].
Social	• Public acceptance of advanced fuels is influenced by trust in responsible actors and perceived benefits. Awareness campaigns can improve acceptance [6]. • Cultural values and norms play a significant role in shaping attitudes towards new technologies, including advanced fuels [31]
Technological	• The Netherlands is leading in sustainable innovation, with significant investments in R&D for renewable energy technologies [32]. • The Netherlands is at the forefront of recycling technologies, holding a significant share of international patents for plastic recycling and bioplastics [32]. • The country is also advancing in the production of synthetic fuels and e-fuels, supported by both national and EU funding [33].
Environmental	• The Netherlands aims for a renewable energy share of 27% in gross final energy consumption by 2030 [34]. • The national target is a 49% reduction in greenhouse gas emissions by 2030 compared to 1990 levels [35].
Legal	• National policy aiming to reduce greenhouse gas emissions by 49% by 2030, with measures to promote renewable energy and advanced fuels [36]. • The Netherlands adheres to IMO regulations, which include measures to reduce greenhouse gas emissions from ships and promote the use of alternative fuels [26]. • Alternative Fuels Infrastructure Regulation (AFIR) requires the Netherlands (like other Member States) to develop infrastructure for alternative fuels, including electric and hydrogen refueling stations, to support the transition to low-emission mobility [25].

Spain	
Political	• The Spain's Circular Economy Strategy promotes the transition to a circular economy, which includes the efficient use of resources and the reduction of waste. The strategy supports the development of biofuels derived from waste products, aligning with the EU's emphasis on advanced biofuels that do not compete with food crops [37]. • The Long-Term Decarbonization Strategy (ELP 2050) sets Spain's vision for achieving a climate neutral economy by 2050 and reducing the GHG emissions by 90% compared to 1990 [38]. • Spain's National Energy and Climate Plan (NECP) targets to promote the use of sustainable biofuels in the transportation sector, including aviation and maritime. The NECP sets a target reaching 42% of renewable energy in final energy consumption by 2030 [39].

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	• The Spanish government launched the Hydrogen Roadmap to promote the development of green hydrogen and focuses on scaling up hydrogen production using renewable energy. The total electrolyser capacity target of Spain is 4GW by 2030 (10% of the EU total). Spain aims to replace 25% of the current 500,000 tons of fossil-based hydrogen consumed by Spanish industry annually, with green hydrogen [40].
Economic	• Spain is one of the largest biofuel producers in the EU with a 500 ktoe production, and the largest user of Annex IX Part A biofuels. In 2022, Spain's biofuels consumption amounted to 1.45 Mtoe [41, 42, 43]. • Spain records the highest volumes of agricultural biomass (20,844 thousand m^3) [42]. • The positive contribution of the NECP to GDP is reinforced, generating an annual increase in GDP of EUR 34.700 billion in 2030 ; this corresponds to an increase in GDP in 2030 by 35 % higher than the foreseen in the 2021-2030 NECP [44]. • Spain should significantly decrease its external energy dependency from 73 % in 2019 [44].
Social	• The NECP proposes a number of measures to increase public awareness and training campaigns or improve access to energy sector information and data [45]. • The activities of Institute for Energy Diversification and Savings (IDAE) include increasing public knowledge and awareness, technical advice, and project financing of technology innovations [45]. • Encourage consumers to choose airlines & shipping companies that use sustainable fuels. • The number of direct & indirect jobs in Spain for the biofuel sector was 14000 in 2020 [46].
Technological	• The Ministry of Science and Innovation (MCIN) is responsible for proposing and implementing the Spanish Government's policy on scientific research, technological development and innovation in all sectors, in coordination with the Ministry for the Ecological Transition and the Demographic Challenge (MITECO) and the other ministerial departments with R&D&I actions, together with its funding agencies and its affiliated bodies [44]. • Spain has several research institutions and universities that are pioneering innovations in second-generation biofuels, waste-to-energy technologies, and synthetic fuels. • Spain was the second European country in terms of installed renewable capacity and electricity generated by wind and solar power [44]. Spain is a leader in Europe in co-processing vegetable oil with fossil diesel at oil refineries to produce renewable diesel; in 2020, 740 thousand tons of capacity and 430 thousand tons of production was achieved.
Environmental	• As indicated in the long-term environmental targets for 2050: (a) up to 90% reduction in GHG emissions compared to 1990 and (b) 100 % renewables on final energy use [38].

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Legal	• The adoption of the 2021-2030 NECP resulted in the submission and adoption of numerous legislative proposals at European level, including the European Climate Law, the Fit for 55 and the REPowerEU packages [44]. • Spain has established Regulations on Biofuel Production and Distribution, ensuring compliance with environmental standards [44]. • The Law 7/2021 of 20 May on climate change and energy transition sets out the need to adopt measures to reduce emissions from fossil fuel consumption in maritime transport and ports, in order to produce zero direct emissions by 2050 [44].

Greece	
Political	• As defined in Greek LTS 2050, Greece aims to achieve carbon neutrality by 2050 in which zero use of nuclear energy and use of Carbon Capture and Storage technology (CCS) are key options [47]. • The Greek NECP sets a target to reduce GHG emissions by 55% by 2030 compared to 1990 levels. Greece targets to increase the share of renewable energy in gross final energy consumption at 35% and the renewable energy share in the transport sector at 19%, by 2030 [48]. • Greece has set an ambitious goal for 2030 as part of its NECP, which targets the installation of 1.7 GW of electrolysers by 2030 (135,000 tons of green hydrogen production) and 30.6 GW of electrolysers by 2050, producing 2.3 million tons of green hydrogen [49].
Economic	• The Greek NECP targets that the use of advanced biofuels in transport is 8.2% by 2030 [12]. • In 2021, the supply of renewable energy and biofuels in Greece was 3.84 Mtoe [50]. • Energy consumed by transport sector in 2030 is expected at 577 ktoe for the maritime and 1096 ktoe for the aviation [51]. • According to the Greek Energy Roadmap to 2050, Greek transport sector will contribute to reduce significantly oil consumption and increase use of biofuels [52]. • Gross domestic expenditure on research and technological developments expected to double until 2030, reaching 0.13% of the GDP in 2030 in the energy-environment sector, compared to 0.06% in 2021 [48].
Social	• The government supports the effort made towards a climate neutral economy, aiming to improve the competitiveness of the economy and of businesses, to create new jobs and to strengthen the role of consumers and the overall functioning of competitive energy markets for the benefit of society [48]. • New institutions, such as energy communities, active consumers and decentralized energy management. as well as the technological development of electricity distribution networks, are expected to play a major role [48]. • The number of direct and indirect jobs in Greece for the biofuel sector were 2500 in 2020 [46].

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Technological	• Greek research centers are urged to apply an open policy that will invite international partnerships with institutions and other States [48]. • In Greece, there is a significant potential for energy crops that can be used to produce liquid biofuels, such as rapeseed and sunflower for biodiesel production, as well as barley, beet, maize and sweet sorghum for bioethanol production [52].
Environmental	• As stated in the revised Greek NECP, the national objective for the RES share in gross final energy consumption by 2030 should be at least 35% [48]. • It is envisaged a GHG emission reduction of more than 56% compared to 2005 by 2030, against a corresponding EU objective of approximately 36% (adjustment of the EU objective of 40% compared to 1990) [48].
Legal	• Greece has already developed and adopted by means of Law 4414/20 the National Strategy for Adaptation to Climate Change, which sets out the general objectives, guidelines and means of implementation of a modern, effective and developmental climate change adaptation strategy within the framework set by the United Nations Convention on Climate Change, EU directives and international experience [48]. • The National Strategy for Adaptation to Climate Change (NSACC) sets the overall objectives, guidelines and tools for implementing necessary climate adaptation measures at national, regional and local levels [48].

Stakeholder Analysis

Stakeholder analysis is a strategic tool used by project managers to identify, understand, and engage the key individuals or groups that can influence or be influenced by a project. The main steps of a stakeholder analysis are to present a comprehensive list of potential stakeholders, followed by a categorization stage based on their influence, interest, and level of participation in the project [53].

One effective method is the influence/interest grid, which divides stakeholders into four categories (see Figure 2) [54]: *(i) High Power, High Interest*; these stakeholders are important to the project's success, and should be prioritized for engagement and communication, *(ii) High Power, Low Interest;* these stakeholders hold significant influence, but they are not be deeply invested in the project, (iii) *Low Power, High Interest;* these stakeholders have a strong interest in the project but possess limited influence over its outcomes, and *(iv) Low Power, Low Interest;* these stakeholders require minimal communication but should still be kept informed about key developments.

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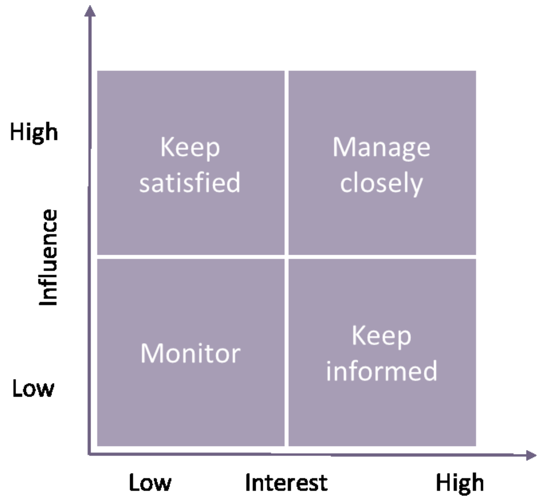

Figure 2. Influence vs. Interest Grid for stakeholder prioritization

In the present Deliverable, the following stakeholder groups have been identified to understand connections and needs: (a) fuel producers & suppliers, (b) airlines & shipping companies, (c) government & regulatory bodies, (d) research & development organizations, (e) technology providers, (f) aircraft & ship manufacturers, (g) customers & end users, (h) environmental groups/NGOs, (i) industry associations and labor unions. The identification of the aforementioned stakeholders provides significant insights into market demand and acceptance, compliance requirements, potential risks, and new links. *Figure 3* depicts a simplified influence vs interest grid.

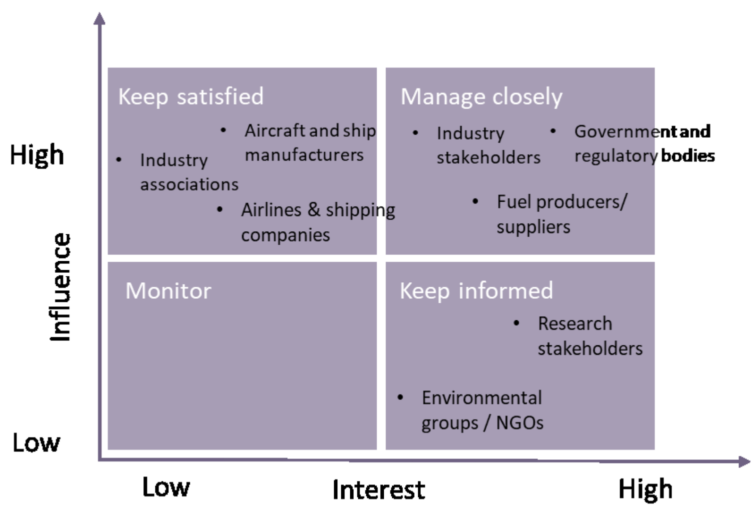

Figure 3 Influence/grid for stakeholders related to the biofuel production

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Potential Stakeholders in EU level

Fuel producers and suppliers, airlines and shipping companies, and environmental groups/NGOs stakeholder groups have been excluded from EU level because these groups primarily operate at the national level.

EU	
Government & Regulatory Bodies	• European Commission • European Environment Agency • European Union Aviation Safety Agency [55]
Key biofuel industry stakeholders	• ETIP Bioenergy [56] • Technology Collaboration Programmes (TCPs) within the International Energy Agency (IEA) [57] • European Biodiesel Board (EBB) [58] • Bioenergy Europe [59]
Research stakeholders	• Joint Research Centre (JRC) [60]
Industry Associations	• FuelsEurope [61] • International Air Transport Association (IATA) [62]

Potential Stakeholders in Germany

Germany	
Fuel Producers and Suppliers	• Wintershall Dea • BAYERNOIL Raffineriegesellschaft mbH • DYNAEnergetics
Airlines and Shipping Companies	• Lufthansa • Eurowings • Condor • Maersk
Government & Regulatory Bodies	• Federal Ministry for Economic Affairs and Climate Action (BMWK) • Federal Environment Agency (UBA) • German Emissions Trading Authority (DEHSt)
Key biofuel industry stakeholders	• Bundesverband BioEnergie e.V. (BBE) • Bundesverband der deutschen Bioethanolwirtschaft (BDBe) • Verband der Deutschen Biokraftstoffindustrie e.V. (VDB) • Deutsche Energie-Agentur GmbH (dena)
Research stakeholders	• Fraunhofer Institute • Max Planck Society • Helmholtz Association • Leibniz Association
Environmental Groups / NGOs	• BUND (Friends of the Earth Germany) • German Environmental Aid Association (DUH)

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Industry Associations	• German Chamber of Commerce and Industry (DIHK) • Federation of German Industries (BDI)

Potential Stakeholders in Austria

Austria	
Fuel Producers and Suppliers	• OMV Group • VERBUND AG • RAG Austria AG
Airlines and Shipping Companies	• Austrian Airlines • Lauda Air • DHL Air Austria
Government & Regulatory Bodies	• Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) • Austrian Energy Agency (Energieagentur)
Key biofuel industry stakeholders	• Agrana Group • BDI-BioEnergy International AG • Energiewerkstatt
Research stakeholders	• Austrian Institute of Technology (AIT) • Graz University of Technology • Joanneum Research
Environmental Groups / NGOs	• GLOBAL 2000 (Friends of the Earth Austria) • ÖKOBÜRO - Alliance of the Environmental Movement
Industry Associations	• Austrian Federal Economic Chamber (WKO) • Austrian Biomass Association

Potential Stakeholders in Netherlands

NETHERLANDS	
Fuel Producers and Suppliers	• SkyNRG [63] • Neste's Rotterdam refinery [64]
Airlines and Shipping Companies	• KLM Royal Dutch Airlines • Transavia • Maersk Line Netherlands • Spliethoff Group
Government & Regulatory Bodies	• Ministry of Economic Affairs (Government of the Netherlands) [65] • Netherlands Standardization Institute [66] • Netherlands Bio-energy Association [67] • Partners for Innovation BV [68] • PBL Netherlands Environmental Assessment Agency [69]

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Key biofuel industry stakeholders	• LyondellBasell Industries [70] • Petroquantum [71] • SkyNRG [63]
Research stakeholders	• BTG Biomass Technology Group [72] • Delft University of Technology [73] • Energy Research Centre of the Netherlands (ECN) [74] • TNO Innovation for life [75]
Environmental Groups / NGOs	• Milieudefensie, Platform Duurzame Biobrandstoffen [76] • Stichting Natuur en Milieu [77]
Industry Associations	• Royal Association of Netherlands Shipowners • Aviation Industry Association Netherlands

Potential Stakeholders in Spain

SPAIN	
Fuel Producers and Suppliers	• Repsol • Cepsa • Disa Corporación Petrolífera
Airlines and Shipping Companies	• Iberia • Vueling • Binter Canarias • MSC (Mediterranean Shipping Company) • Grupo Boluda Corporación Marítima • Grupo Suardiaz
Government & Regulatory Bodies	• APPA Spanish Renewable Energy Association [78] • AVEBIOM - Asociación Espanola de valorización energética de la biomasa [79] • BIOPLAT - Spanish Biomass Technology Platform [80] • IDEA [81], • SENASA [82]
Key biofuel industry stakeholders	• Ciudad de la Energía (CIUDEN) • TECNALIA Energy • Center for Energy, Environmental and Technological Research (CIEMAT)
Research stakeholders	• Fundación Ciudad de la Energía (CIUDEN) • TECNALIA Energy • Center for Energy, Environmental and Technological Research (CIEMAT)
Aircraft & Ship Manufacturers	• ITP Aero • Aciturri Aeronáutica • S.L.U. • Navantia • Astilleros de Mallorca

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	• Astilleros Gondán
Environmental Groups / NGOs	• Ecologistas en Acción • Fundación Biodiversidad, • Asociación Española de Bioenergía (AEBi)

Potential Stakeholders in Greece

GREECE	
Fuel Producers and Suppliers	• HELLENiQ Energy [83] • Motor Oil (Hellas) [84]
Airlines and Shipping Companies	• Aegean Airlines, Olympic Air • Maran Gas Maritime Inc. • Tsakos Shipping & Trading S.A.
Government and Regulatory Bodies	• Ministry of Infrastructure and Transport [85] • Ministry of Environment and Energy [86] • Hellenic Biomass Association (HellaBiom) [87]
Research & Development Organizations	• National Technical University of Athens (NTUA) [88] • Centre for Research and Technology Hellas (CERTH) [89]
Industry Associations	• Union of Greek Shipowners [90]

Process Analysis

The Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is employed to investigate the current state of fast pyrolysis and gasification technologies for biofuel production [91]. While PESTEL analysis only concentrates on the external factors, SWOT analysis also investigates the internal and external strengths and weaknesses factors that might affect the deployment of renewable energy sources and associated technologies [92]. The main objective of a SWOT analysis is to identify the fundamental internal and external factors that contribute significantly to achieving the objective. The SWOT analysis groups key pieces of information into two main categories: (a) internal factors, which are related to the strengths and weaknesses internal to the organization/project, and (ii) external factors, which are associated with the potential opportunities and threats presented by the external environment. The results are often demonstrated in the form of a matrix.

The methodology applied in the present study includes the performance of the SWOT analysis of the (i) pyrolysis (see **Error! Reference source not found.**) and (ii) gasification (see **Error! Reference source not fo**

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und.) technologies, providing integrated information on the strengths and weakness inherent to the project, as well as on the opportunities and threats in the global external environment.

Table 1: SWOT analysis for the pyrolysis technology [93, 94, 95, 96]

Pyrolysis Process	
Strengths	**Weaknesses**
Flexibility: Pyrolysis can be adapted to different feedstocks, e.g., agricultural residues, municipal solid waste; this adaptability makes it suitable for different regions and industries, enhancing its flexibility and sustainability. **High Energy Efficiency:** Ability of the process to extract & exploit the energy stored in the biomass feedstock effectively. **Robust & compact process:** Pyrolysis does not require gas-carrier. **Heat recovery potential:** Excess heat generated can be utilized for drying process **Lower emissions:** The biomass pyrolysis process results in lower GHG emissions, as compared to conventional fossil fuels. This reduction is important for environmental sustainability and compliance with emission standards. **Hazardous organic solid waste mitigation:** Pyrolysis prevents the formulation of hazardous nitrogenous, halogenated & sulfur compounds. **Economic & Environmental Potential:** Pyrolysis exploits renewable resources & waste materials, thus contributing to economic & environmental benefits.	**Quality control of feedstock procurement:** (i) different suppliers - quality control, (ii) Sustainability issues-feedstock traceability, (iii) cost of feedstock. **Feedstock Processing Requirements:** Energy consuming requirements for pyrolysis inputs (low moisture content and very small particle size). **Catalyst Deactivation & Regeneration:** The formulation of tar and char during biomass high-temperature pyrolysis can cause catalyst deactivation. Catalyst Regeneration is required to reduce operating costs and prevent environmental contamination. **Syngas Quality:** The composition of biomass may have an effect on the quality of syngas produced from the pyrolysis process. **Pollutant management requirement:** Flue gases produced may require additional purification systems, that might lead to further cost increment. **Economic aspects:** High initial investment, and high operating and energy costs.
Opportunities	**Threats**
Production of valuable by-products: Pyrolysis process generates bio-oil, biochar, and syngas. Bio-oil can be used as a fuel or further refined into chemicals, syngas, a mixture of carbon monoxide and hydrogen, can be used as a fuel for electricity generation or converted into chemicals and biofuels, whereas biochar serves as a soil amendment, thus, enhancing fertility and sequestering carbon. **Small-scale and remote operations:** Pyrolysis can be applied in small-scale, remote locations, thus, increasing the energy density of biomass and decreasing transport costs. This scalability makes	**Heat & mass transfer:** Accurate estimates for heat and mass transfer parameters (e.g., thermal conductivity, diffusivity) are lacking despite the fact that biomass conversion in commercial pyrolysis reactors is controlled by transport. **Standards:** Standards & specifications for pyrolysis oil are still under development **Cost competitive fuel processing including transportation:** (i) where are the best preconditions for processing; (ii) process integrations to maximize energy efficiency. **Biomass availability and bioenergy market competition**: Secure a reliable and cost-effective supplies of biomass feedstock, produced in a

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it an attractive option for decentralized energy production. **Agricultural Fertilization potential:** Ash produced from pyrolysis be used as a fertilizer.	sustainable manner over the operating life of the plant. **Impurities in feedstock:** Biomass feedstock may contain corrosive compounds or impurities; thus, gas cleaning strategies are required.

Table 2: SWOT analysis for the gasification technology [93, 94, 97, 98, 99, 100, 101, 102, 103]

Gasification Process	
Strengths	**Weaknesses**
Effect of gasifier temperature: Higher gasifier temperatures promote the heat absorption reaction in the tar cracking reaction, resulting in lower tar content and raising gas yield. **Flexibility:** Gasification can be adapted to different biomass feedstocks, such as agricultural residues, municipal solid waste, making it suitable for different industries & regions, thus, improving its flexibility and sustainability. **Biofuels:** High performance biofuels (quality and yield); **Process:** No oxygen is required in biomass gasification process (lower capital costs and efficiency losses). **Maturity level:** The gasification technology is already available at commercial scale. **Environmental Potential:** Biomass gasification enables production of renewable power/heat/fuels/chemicals. This technology is carbon neutral and clean biofuels could be produced in this way. **Prevention of hazardous compound formation** (for instance, nitrogenous, halogenated & sulfur compounds)	**Biomass Feedstock:** Biomass does not show stable behavior. Biomass characteristics might affect plant performance & alter gasification performance. **Biomass Pre-treatment:** Pretreatment technologies are capital-intensive. Pre-treatment can be energy intensive and requires specialized equipment. **Process:** Based on the required pressure conditions for hydrogen production, there are operational, design, and scaling challenges for gasifiers. **Tar production:** Tar production is a significant problem during the gasification process and impurities must be removed for further applications. **Carbon deposition & catalyst deactivation:** Carbon deposition negatively affects the performance of a catalyst in gasification.
Opportunities	**Threats**
Production of syngas: Syngas generated via gasification can be converted into various synthetic fuels and chemicals. **Integration in existing refineries:** Feasibility of integrating gasification systems into conventional oil refineries for the production of synthetic biofuels. **Sustainability:** Biomass gasification contributes significantly to reducing GHG emissions,	**Agglomeration:** Operational issues associated with biomass gasification, encompassing sedimentation, erosion, fermentation, accumulation, and corrosion, pose considerable handicaps to the economic extension of the gasification technology. **Biomass prices:** Uncertain biomass prices may cause investment risk, which hampers the development of gasification technology. Investors are reluctant to invest in large-scale gas technology.

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promoting energy security, and supporting the transition to a low-carbon economy.	**Supply chain management:** A key factor for biomass- based projects is the provision of biomass, which has a significant impact on other factors. **Financial barrier:** Gasification technology requires high initial capital, financial support & government policies. **Need for infrastructure to support the large-scale production and distribution of syngas.** **Further Research:** Further research, investment, and infrastructure development are needed to overcome the challenges associated with the gasification technology.

Product Analysis

Product analysis involves a comprehensive evaluation of a product's features, functionality, and overall performance. This process enables managers to make informed decisions, enhance user experience, and maintain competitiveness in the market. A thorough product analysis often extends to assessing competitors’ products, as well as identifying gaps in the market that may present opportunities for new product development or feature enhancement. This systematic examination allows organizations to address potential issues, streamline existing products, and discover ways to maximize returns on investment. When embarking on the product analysis process, several essential components need to be addressed. These include the function and purpose of the product, examining materials and methods used in production, expected consumers, advantages of the product compared to similar products and the cost competitiveness [97].

In this deliverable, product analysis provides valuable insights on all aspects of biofuels performance to inform decision-makers/relevant stakeholders. Biofuel production using agricultural waste materials as a source of energy sustainability is a significant and promising approach to address energy & environmental challenges. This process involves converting various types of agricultural residues and by-products into biofuels, which can be used as renewable and cleaner alternatives to fossil fuels. Regarding the entire supply chain of biofuels, the proper biomass feedstock collection and storage are important to prevent degradation and maintain the quality of the feedstock. It is worth mentioning that the uncontrolled loss of biomass due to degradation may lead to physical and mechanical challenges with biomass handling, size reduction, and preprocessing. Degradation in storage can also result in biomass that is more recalcitrant to chemical and enzymatic approaches to depolymerization, and ultimately results in lower

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product yields. Therefore, the consistent biomass feedstock quality is very important to achieve high product yield and maximum onstream time. To preserve, or even improve, feedstock quality, material compatibility, temperature and environmental control, as well as regulatory compliance (storage facilities should comply with environmental regulation) should be considered [98].

The development of biofuel generations reveals different feedstock sources, including lignocellulosic biomass (such as forestry byproducts and wood) and waste biomass (e.g., municipal solid waste), and associated technology paths. The adaptability of biofuel production technologies to different biomass feedstocks makes them suitable for different regions and industries, enhancing their flexibility and sustainability from a circular economy perspective. The technology paths employed in biofuel production vary depending on the type of feedstock and the desired end product. Thermochemical conversion processes, mainly pyrolysis and gasification, utilize high temperature conditions and catalysts to heat or oxidize the biomass resources, resulting in the production of synthetic gas, which, in turn, can be converted into various synthetic fuels and chemicals [99, 100, 101]. Especially concerning catalysts, their utilization in thermochemical conversion processes can reduce the reaction time use of catalysts in gasification can reduce the reaction time and temperature, leading to an increase in useful gases in the product gas. The main criteria for a good catalyst include: (i) providing a suitable syngas ratio for the intended process, (ii) resistant to deactivation, and (iii) easy to regenerate [102]. The fundamental principle of thermochemical processing is to decrease the oxygen content of raw biomass, thereby enhancing the energy density and creating carbon-carbon bonds to increase the molecular weight of the final fuel [103]. Thermochemical conversion processes are preferred over biochemical techniques, due to their versatility, efficiency and shorter reaction times. However, challenges such as feedstock composition variability, high production and development costs, technological complexities, and issues related to climate change conditions and storage stability must be addressed.

Biofuels target to industries and individuals seeking sustainable energy solutions that can be seamlessly integrated into existing infrastructure with minimal additional investment. This includes transportation companies, industrial operators, and governments aiming to meet environmental targets while reducing their carbon footprints. Biofuels can be blended with fossil fuels or used as drop-in fuels without technical modification in the engine [46]. As defined in the ReFuelEU Aviation regulation, fuel suppliers should blend increasingly higher levels of sustainable aviation fuels and, from 2030, synthetic fuels with existing jet fuel supplied at EU airports. They must incorporate 6% in 2030 and 70% in 2050 [104]. In the framework of the 2030 Climate Target Plan (CTP) and in support of the Sustainable and Smart Mobility Strategy,

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renewable and low-carbon fuels should represent between 6% and 9% of the international maritime transport fuel mix in 2030 and between 86% and 88% by 2050 to contribute to the EU economy-wide GHG emissions reduction targets [105].

The evaluation of the competitive advantages of biofuels is a significant step in the product analysis. From an environmental perspective, biofuels produce low amounts of sulfur and provide about 60–100% CO_2 reduction compared with conventional fossil fuels (e.g., heavy fuel oil) [106]. Furthermore, biofuels are often considered carbon neutral because the feedstock absorbs CO_2 from the atmosphere during its growth period. However, it is important to consider the entire life cycle of biofuel production in order to ascertain its viability, because notable amounts of both materials and energy are consumed, and significant amounts of GHG emissions are involved in the collection, transportation and pre-treatment processes biomass feedstock [107]. Research has identified the need for life cycle assessment studies, but it has now been noted by regulatory bodies as well. For instance, in the FuelEU maritime proposal, the EU has employed a "well-to-wake" (WtW) methodology that splits the life cycle of a fuel source into extraction of raw materials to a production part and an end-use part. Similarly, in aviation, the International Civil Aviation Organization (ICAO) has adopted the use of LCA in their guidelines [107].

In addition to the environmental benefits, cost competitiveness is also an important factor to be considered in product analysis. Biofuels production costs can vary widely by feedstock, conversion process, scale of production and region. These differences reflect many factors, such as scale, process efficiency, feedstock costs, capital and labor costs, co-product accounting, as well as government policies (e.g., subsidies and incentives) [108]. The major economic factor to consider for input costs of biofuel production is the feedstock, which accounts for about 75-80% of the total operating cost. Other important costs are labor, and catalyst, which must be added to the feedstock [109]. As demonstrated in the relevant literature, the cost of large-scale production of biofuels is currently high in developed countries. In particular, the production cost of biofuels may be three times higher than the one of petroleum fuels, without, however, considering the non-market benefits. Conversely, in developing countries, the costs of producing biofuels are much lower than in the OECD countries and very near to the world market price of petroleum fuel [107, 108, 109, 110]. Nevertheless, the cost-effectiveness of biofuels is expected to improve with technology evolution and production scaling up. In general, the economic advantages of biofuel industries would include an increased number of rural manufacturing jobs, an increased income taxes, investments in plant and equipment, reduced a country's reliance on crude oil imports and supported agriculture by providing a new labor and market opportunities for domestic crops.

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The socio-economic impacts on the local economy arising from the exploitation of transport biofuels instead of conventional fossil fuels are also very important. These impacts include direct and indirect differences in the jobs, income, and gross output. Furthermore, important socioeconomic impacts are related to investment in new power plants, including increases in employment, output, and income in the local and regional economy. Increases in these categories occur as labor is directly employed in the construction and operation of a plant, as local goods and services are purchased and utilized. Last, but not least, the potential for reduced costs of renewable transport fuels and conservation of scarce fuel resources results in significant reductions in fuel usage. In addition to the aforementioned environmental, economic and social benefits, the deployment of renewable resources will have health, safety and other benefits.

It can be concluded that that to achieve scaling up of biofuel, strategies are recommended, covering areas such as enhanced stakeholder collaboration, advanced process intensification, supportive policy frameworks, innovative financing models and strategic marketing initiatives.

Conclusion

The BioTheRoS project offers important progress in addressing the challenges of scaling sustainable biofuels for the aviation and shipping industries. Through this detailed report, utilizing both PESTEL and SWOT analyses, the market assessment provides a comprehensive understanding of the external factors—political, economic, social, technological, environmental, and legal—that influence biofuel adoption in key European markets. Project countries, Germany, Austria, the Netherlands, Spain, and Greece, have shown varying levels of readiness and potential for biofuel integration, with a range of opportunities and obstacles highlighted. For instance, while Germany and the Netherlands have made significant strides in technological development and infrastructure readiness, other regions face economic and regulatory challenges that must be addressed to facilitate biofuel uptake.

The report further exposes the important role of stakeholder collaboration in overcoming these challenges. The involvement of fuel producers, regulatory bodies, environmental groups, and research institutions is essential to creating a cohesive strategy for advancing biofuel technologies. Collaboration between national governments and the European Union is also key to harmonizing regulatory frameworks, securing financial incentives, and fostering innovation. The stakeholder analysis emphasizes the importance of engaging key industry players, including airlines, shipping companies, and fuel suppliers, to ensure alignment between market demand and supply capabilities.

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In terms of technology, the report highlights the strengths and weaknesses of the main biofuel production methods—pyrolysis and gasification. Both processes show promising potential in terms of energy efficiency and environmental benefits. However, they also present challenges about biomass itself, technical complexities related to feedstock quality and process optimization. The ongoing development of these technologies, supported by EU and national funding initiatives, will be crucial in making biofuels a competitive option on a larger scale.

By addressing the identified challenges and focusing on opportunities, the project aims to foster the transition to cleaner energy sources in the aviation and shipping industries, contributing to the broader goals of carbon neutrality and environmental sustainability in the EU.

In the updated version of this assessment, the market analysis will be expanded to include a more detailed evaluation of potential risks. Bases on these estimated potential risks, strategic recommendations that offer actionable strategies will be developed.

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