Small Business Standards

Empowering SMEs in the Renewable Energy Sector

Unlocking Opportunities Through Standardisation Strategies

MARCH 2025

Empowering SMEs in the Renewable Energy Sector through Standardisation

Author: **Valentina Couceiro**

Supervisor: **Maitane Olabarria**

Small Business Standards (SBS) is the European association representing and supporting small and medium-sized companies (SMEs) in the standardisation process, both at European and international levels.

Rue Jacques de Lalaing 4 - 1040 Brussels, Belgium

info@sbs-sme.eu

Transparency Register 653009713663-08

Co-financed by the European Union and EFTA

EXECUTIVE SUMMARY

As the renewable energy sector expands, Small Business Standards (SBS) aims to support its members by providing essential knowledge on the role of standards in the growth of renewable energies and helping them navigate the ongoing standardisation work related to this area.

This report provides a comprehensive overview of the role of Small and Medium Enterprises (SMEs) in the renewable energy value chain, and identifies the standardisation bodies, technical committees and working groups where their involvement is most needed. It delves into the market share of SMEs across diverse renewable sectors — solar photovoltaic, solar thermal, hydropower, wind, geothermal, wave energy, biofuels, and hydrogen — highlighting opportunities for growth and collaboration.

Key findings reveal that most SMEs in the European photovoltaic sector are primarily engaged in module installation, with some venturing into the production and manufacturing of cells. In stark contrast, the solar thermal value chain sees SMEs actively involved across all stages, including the sourcing of raw materials. In hydropower, SMEs emerge as pivotal contributors, leveraging operational expertise and technological innovation to maintain small-scale plants.

In geothermal energy, SMEs play an important role across various sectors, including service providers, drilling and equipment manufacturers.

In the hydrogen domain, while large corporations dominate large-scale production, SMEs are pivotal in decentralised hydrogen initiatives. They excel in scalable technologies like water electrolysis and aluminium oxidation, while also contributing specialised services in hydrogen storage and transportation, such as pipeline maintenance and material innovation for cryogenic systems.

SMEs in biofuels are predominantly involved in raw material extraction rather than the biomass transformation into biofuels.

Regarding wind energy, SMEs are designing, constructing and maintaining wind turbines, as well as developing lifting equipment for wind turbines. While in ocean energy, SMEs are more likely to participate in wave technologies than in tidal technologies.

This report has not addressed or has only superficially explored topics such as batteries, energy storage, grid connections, and the management of energy consumption. These areas could be further explored in potential future reports, possibly in collaboration with other organisations.

SBS currently participates in relevant technical committees and working groups related to photovoltaic panel installation: CEN/TC 128/WG 3 and CLC/TC 64/JWG 64/82. However, SBS could enhance its engagement in the renewable energy sector. The following recommendations aim to ensure stronger SME representation in standardisation:

1. **Strengthen SME participation in standardisation** by finding experts in the areas related to the following working groups:
   - ISO/TC 160/WG 9 and CEN/CLC JTC 10/WG 5 for solar PV
   - ISO/TC 180/WG 4 and CEN/TC 312/WG 1 for solar thermal energy
   - ISO/TC 339 for hydropower
   - CEN/TC 10/WG 11 for wind energy
   - CEN/TC 151/WG 3 for geothermal energy
   - IEC TC 114 for ocean energy
   - ISO/TC 238/WG 7 and CEN/TC 335 for biofuels

   And by collaborating with the following associations:
   - SolarPower Europe for solar PV
   - SolarHeat Europe for solar thermal energy
   - European Renewable Energy Federation for hydropower and for other small-scale operators of renewable energy power plants
   - HydrogenEurope for hydrogen
   - European Geothermal Energy Confederation for geothermal energy
   - European Biodiesel Board for biofuels

   Wind Europe and Ocean Energy Europe did not engage in discussions during this study, but potential opportunities for dialogue and collaboration could be explored in the future.

2. **Raise awareness and capacity building** actions that could be undertaken include:
   - Developing practical guides in collaboration with sectoral stakeholders like Hydrogen Europe.
   - Promoting certifications such as CEN Solar Keymark for solar thermal energies.
   - Organising an event on standardisation for SMEs in the renewable energy sector.

3. **Advocate for SME-friendly policies and funding** including:
    - Streamlined permitting processes for hydropower and geothermal projects.
    - Tailored financial support, such as travel grants for international standardisation meetings, developed in partnership with other organisations like HydrogenEurope, which supports this initiative.

By implementing these recommendations, SBS can empower SMEs to overcome barriers, drive innovation, and contribute to a sustainable and inclusive renewable energy landscape in Europe.

TABLE OF CONTENT

ABBREVIATIONS

BoS: Balance of System

BIPV: Building-Integrated Photovoltaic

CEN: European Committee for Standardization

CENELEC: European Committee for Electrotechnical Standardization

EU: European Union

EPBD: Energy Performance of Buildings Directive

FCH: Fuel Cells

GHG: Greenhouse Gases

HAWTs: horizontal-axis wind turbines

IEC: International Electrotechnical Commission

ISO: International Organization for Standardization

IWG: Implementation Working Group

LOHC: Liquid Organic Hydrogen Carriers

MOF: Metal Organic Framework

PV: Photovoltaic

PtG: Power-to-Gas

RED: Renewable Energy Directive

R&D: research and development

SBS: Small Business Standards

SHP: Small Hydropower Plant

SMEs: Small and Medium-sized Enterprises

TC: Technical Committee

UDB: Commission's Union Database for Biofuels

USA: United States of America

VAWTs: Vertical-Axis Wind Turbines

WFD: Water Framework Directive

WG: Working Group

TABLE OF FIGURES.

TABLE OF TABLES.

1. INTRODUCTION

The excessive utilisation of fossil fuels emitting greenhouse gas (GHG) is one of the principal causes behind climate change (Clean Hydrogen Partnership, 2022). Phasing out fossil fuels is hence necessary to ensure human liveable conditions. Additionally, European dependence on expensive imported Liquefied Natural Gas combined with slow and suboptimal investment in infrastructure for renewables and grids has weakened the EU's bargaining power while driving electricity prices to levels 2-3 times higher than those in the United States of America (USA) (Draghi, 2024).

Decarbonisation is an opportunity for Europe to lead in the shift towards secure, low-cost clean power generation (Draghi, 2024). To succeed, the EU needs a coherent strategy that includes standards promoting innovation and enhancing market competitiveness in the renewable energy sector, particularly for SMEs, which represent 98% of companies in the EU (Draghi, 2024; Katsinis et al., 2024).

Small Business Standards (SBS) aims to support its members in gaining a deeper understanding of the renewable energy sector, enabling them to identify key standardisation areas relevant to SMEs. Additionally, SBS aims to expand its collaboration with renewable energy industry associations representing SMEs to ensure stronger SME interests' representation in relevant standardisation work.

To this end, SBS has developed this report which summarises the role of SMEs in the renewable energy value chain and analyses current standardisation activities most relevant to SMEs in this area. The methodology involved a thorough review of the most up-to-date and reliable documents, information about Technical Committees (TCs) and Working Groups (WGs) established by key standardisation bodies and 13 interviews with experts from different sectors.

The report focuses on the supply chain of various renewable energy sectors, including solar photovoltaic, solar thermal, hydropower, wind, geothermal, wave energy, biofuels, and hydrogen. However, the report has not addressed or only superficially covered topics such as batteries, energy storage, grid connections, and the management of energy consumption. SBS could explore these areas in future reports, possibly in collaboration with other organisations.

2. SECTORAL ANALYSIS OF RENEWABLE ENERGY INDUSTRIES

This chapter examines the value chain and various technologies associated with each previously mentioned energy source. It also explores the involvement of SMEs within these value chains, the EU's strategic direction in the specific energy sector, and the relevant TCs. Finally, the chapter addresses the challenges SMEs face, with a focus on how standards could potentially offer solutions.

2.1 SOLAR PHOTOVOLTAIC (PV) ENERGY

The Solar PV Energy and its technologies

The solar PV industry involves several key stages (see **Figure 1**):

- Raw material extraction, like polysilicon or monocrystalline silicon.
- Transformation of these materials into ingots, the bulk form of crystalline silicon before it is thinly sliced into wafers
- Creation of solar cells -- the individual components that convert sunlight directly into electricity
- Assembling of interconnected cells into encapsulated and protected structures known as panels.
- Installation of the panels.
- Developing supporting Balance of System (BoS) hardware, such as racking systems and inverters, to connect the energy to the grid.

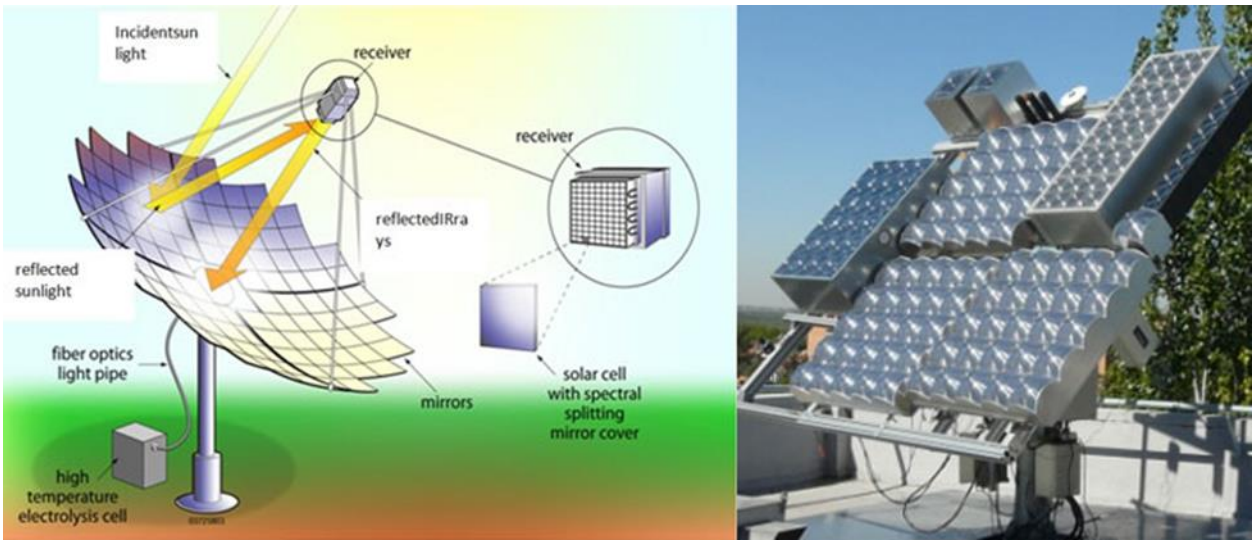
Figure 1: Solar PV Value Chain

Source: Office of Energy Efficiency & Renewable Energy (USA), 2024

Other indirect activities relating to the solar PV sector include:

- Solar concentrators, devices that use trackers to follow the sunlight, capturing as much solar energy as possible to convert into electricity (De Dricus, 2023; see **Figure 2**). Since solar concentrators only work with direct sunlight, their effectiveness is limited to clear sunny locations (De Dricus, 2023).
- Secondary cells and batteries.
- Electrical energy measurement and control

Figure 2 PV Concentrator



Source: De Dricus, 2023

Presence of SMEs in Solar PV

European SMEs play an essential role in the solar PV sector, despite challenges from lower-cost Chinese production and increasing competition from the USA (SolarPower Europe, 2024; European Solar Manufacturing Council, 2023). Most PV raw materials are sourced from Asia, where a few large companies dominate the market (Green Rhino Energy Ltd, 2016). In Europe, SMEs are particularly active in module installation, with some also involved in producing modules and manufacturing cells (Sino Voltaics, 2024; VC, Interview 7b, 2024).

Balance of System (BoS) components, such as racking systems and inverters, account for over half the total cost of smaller PV systems, with proprietary designs limiting SME participation (Franz et al., 2022). However, low-voltage inverters used in

smaller installations provide an entry point for SMEs (Roots Analysis, 2024; VC, Interview 7b, 2024). In Europe, several SMEs, especially in Germany, Spain, and Austria, manufacture BoS components, indicating a strong regional presence (VC, Interview 7b, 2024).

In niche areas, SMEs specialise in innovative products such as building-integrated photovoltaic (BIPV) glass, which integrates solar technology into building facades and windows. These SMEs focus on custom, high-end applications, typically not served by larger companies, such as stadiums and unique architectural projects (VC, Interview 9, 2024).

Additionally, SMEs play a critical role in the end-of-life recycling sector for solar panels, a growing area with underdeveloped standards, presenting an opportunity for SME-driven standardisation efforts (VC, Interview 7b, 2024).

While the upfront costs for solar concentrators limit SME participation, opportunities remain within specific segments of the PV supply chain where customisation and regional manufacturing advantages are valued, indicating their presence in the industry (EconMarketResearch, 2023; VC, Interview 13, 2024). For secondary cells and batteries, SME involvement depends on the type of batteries. Lead-acid and lithium-ion batteries are more likely to involve SMEs while flow batteries are less likely (EBP US, Inc., 2022; Reinsch et al., 2024; Scott, 2023).

Additionally, the IEA states that SMEs are often present in activities relating to energy efficiency and trackers, therefore, linking them to electrical energy measurement and control (IEA, 2022).

In conclusion, most SMEs in the PV sector in Europe are involved in module installation, with some also producing them and, in some cases, manufacturing cells. As in other sectors, they tend to focus on niche activities within the industry.

EU Policy and legislation affecting PV Solar Energy

The EU has positioned solar PV energy at the core of its renewable energy transition, with the REPowerEU plan setting ambitious targets to expand capacity to over 320 GW by 2025 and nearly 600 GW by 2030 (European Commission, 2024a).

The European Commission launched the EU Solar Energy Strategy in May 2022 to meet its targets (European Commission, 2024a). This strategy focuses on leveraging rooftop solar potential by requiring new buildings to be ‘solar-ready’ and gradually installing solar systems on public buildings from 2027 (European Commission, 2024a). It also addresses the skills gap in the renewable energy sector through *the EU Large-Scale Skills Partnership*, which fosters workforce development to support solar PV expansion and job creation (European Commission, 2024a). Additionally, the *EU Solar PV Industry*

Alliance seeks to enhance Europe's domestic manufacturing capabilities, diversify supply chains, and promote sustainable solar technologies (European Commission, 2024a).

In addition to these initiatives, the European Solar Charter, signed in April 2024, outlines voluntary actions to further support the European PV sector. Signed by 23 EU countries, industry representatives, and the European Commission, the Charter reaffirms the EU's commitment to solar energy expansion and bolsters efforts to increase the solar panel manufacturing capacity within Europe (European Commission, 2024a).

Several European countries have emerged as leaders in the PV industry. Germany remains the frontrunner with 14 GW of new solar installations in 2023 (SolarPower Europe, 2024). Other significant contributors include Italy, whose solar market doubled to 4.9 GW, and Austria, which experienced an impressive 114% market growth, reaching 2.2 GW in 2023 (SolarPower Europe, 2024). However, despite these record numbers, SolarPower Europe forecasts a slowdown in growth from 2024 onwards (SolarPower Europe, 2024).

The regulatory framework for solar PV energy in Europe is governed by legislation focused on sustainability, energy efficiency, and environmental protection, particularly the Eco-design Directive (Directive 2009/125/EC), the EU Energy Labelling Regulation (EU) 2017/1369, the Energy Performance of Buildings Directive (EPBD) 2024/1275/EU and the Eco-design Directive and recently adopted Eco-design Regulation (EU) 2024/1726.

The implementation of the Eco-design Directive is supported by standards, which serve as a key tool to ensure compliance with energy efficiency requirements for energy-related products. As outlined in Recital 31, once a standard is published in the *Official Journal of the European Union*, compliance with it establishes a presumption of conformity with the requirements of implementing measures. These standards also play a critical role in guiding manufacturers, particularly for measuring, testing, and developing ecological product profiles, as described in Recital 32. The Directive explicitly supports alignment with international standards, such as ISO 14040[1], and emphasizes synergies with other legislative instruments to ensure coherent requirements for manufacturers.[2] Additionally, Article 10 details the processes for preparing, monitoring, and revising standards to ensure they meet the Directive's objectives. The Eco-design Regulation (EU) 2024/1726 provides transitional measures under Article 79, allowing the continued application of the Eco-design Directive's provisions for PV panels until 31 December 2026. This ensures ongoing initiatives are not disrupted. Together, these instruments establish

[1] ISO 14040 was developed byTechnical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*, in collaboration with CEN/SS S26, *Environmental management*.
Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products [2009] OJ L285/10, Recital 33

[2] Ibid., Recital 35

a comprehensive standards and regulatory framework for PV systems regarding energy efficiency.

The EU Energy Labelling Regulation (EU) 2017/1369 establishes energy labelling for energy-related products, including solar PV systems, enabling consumers to make informed choices.[3] Article 13 requires the Commission to publish references to standards in the *Official Journal of the European Union*, presuming conformity for products meeting these standards during assessments. These standards must also consider real-life usage, maintain reliability, and be cost-efficient for SMEs.

The EPBD (EU) 2024/1275 establishes requirements to improve the energy performance of buildings, including provisions for integrating renewable energy such as solar PV.[4] Article 10 focuses on optimising solar energy in buildings. Member States must ensure new buildings are designed to maximize solar energy generation potential, considering site-specific solar irradiance.[5]

Additionally, the streamlined permit-granting process in Article 16d of Directive (EU) 2018/2001 and the simple-notification procedure under Article 17 of the same Directive apply to solar equipment installations.[6] Deployment deadlines for suitable solar installations are specified as follows:

- By 31 December 2026, on all new public and non-residential buildings over 250 m².[7]
- For existing public buildings exceeding 2,000 m², 750 m², and 250 m² by 31 December 2027, 2028, and 2030, respectively.[8]
- By 31 December 2027, on existing non-residential buildings over 500 m² undergoing major renovations.[9]
- By 31 December 2029, on all new residential buildings and new roofed car parks adjacent to buildings.[10]

National building renovation plans must include measures to support solar installations.[11] Criteria for implementing these obligations, including exemptions, must be publicly available and consider technological neutrality, structural integrity, green roofs,

[3] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU [2017] OJ L198/1, Art. 1(1), Art. 2(1)
[4] Directive (EU) 2024/1275 of the European Parliament and of the Council of 15 May 2024 on the energy performance of buildings (recast) [2024] OJ L158/102., Art. 1(2)(f)
[5] Ibid., Art. 10(1)
[6] Ibid., Art. 10(2)
[7] Ibid., Art. 10(3)(a)
[8] Ibid., Art. 10(3)(b)
[9] Ibid., Art. 10(3)(c)
[10] Ibid., Art. 10(3)(d)–(e)
[11] Ibid., Art. 3

and roof insulation.[12] Stakeholder involvement is required to address issues such as grid stability. Finally, Member States must establish administrative, technical, and financial frameworks to support solar deployment in buildings, including integration with technical building systems or efficient district heating.[13] This is all supported by standards as Annex I mandates that Member States describe their national energy calculation methodologies based on key European standards, including (EN) ISO 52000-1[14] and related standards, or their successors.

Standardisation work on Solar PV

This section presents the Technical Committees (TCs) and Working Groups (WGs) relevant to SMEs in the solar PV sector, starting with those directly related to the sector (see **Table 1**), followed by those indirectly related (see **Table 2**). The committees highlighted in blue indicate the TCs in which SBS participates.

Table 1 Technical Committees on Solar PV

TC	Scope	WGs
CLC/TC 82 'Solar PV energy systems'	PV conversion systems of solar energy into electrical energy and for all elements in the entire PV energy system.	WG 1 Wafers, cells and modules; WG 2 BoS components and systems
IEC/TC 82 Solar PV energy systems	Systems of PV conversion of solar energy into electrical energy and for all the elements in the entire PV energy system.	WG 1 Glossary; WG 2 Modules; WG 8 PV cells
ISO/TC 180 Solar energy	Solar energy (PV and thermal) utilisation in space and water heating, cooling, industrial process heating and air conditioning.	AHG 1 Measurement of CO2; SC-1 Climate - Measurement and data
ISO/TC 160 Glass in building	Appearance, durability and safety, test methods and designation for laminated solar PV glass for use in buildings.	WG 9 Laminated solar PV glass for use in buildings

[12] Ibid., Art. 10(4)
[13] Ibid., Art. 10(5)
[14] ISO 52000-1 was prepared by CEN/TC 371, *Energy Performance of Buildings* in collaboration with ISO/TC 163, *Thermal performance and energy use in the built environment*, and ISO/TC 205, *Building Environment Design*

Table 2 Technical Committees with related work to Solar PV

TCs	Scope	WGs
CEN/TC 128 - Roof covering products for discontinuous laying and products for wall cladding	Structural design for the safety and serviceability of the connection between solar energy panels mounted on flat or pitched roofs.	WG 3 - Renewable energy systems for roofs (**SBS is present in WG 3)**
CEN/TC 371 Energy Performance of Buildings	Guidance and requirements to be met by EPB standards	WG 1 EPBD Standards group; WG 5 Operational rating of energy performance of buildings
ISO/TC 207 Environmental management	Environmental and climate impacts, including related social and economic aspects, in support of sustainable development.	SC 5 Life cycle assessment **(SBS is present in SC 1 but not in SC 5)**
CLC/TC 21X Secondary cells and batteries	Performance, safety, and testing of secondary batteries (rechargeable batteries). Mirror Committee of IEC/TC 21	WG 1 Safety requirements on batteries and battery installations; WG 6 Batteries in Stationary storage applications
IEC/TC 21 Secondary cells and batteries	Requirements, safety, performance, testing, safety of installation, maintenance and disposal for all types of secondary batteries including for storage of energy from renewable sources.	WG 2 Starter and Auxiliary batteries; WG 3 Traction and stationary batteries; WG 8 Safe operation of batteries; WG 11 Secondary high temperature cells and batteries
CLC/TC 64 Electrical installations and protection against electric shock	Safety requirements in installation and co-ordination of electrical equipment	JWG 64/82 Installation of PV – Equipment **(SBS is present in this JWG)**

IEC/TC 13 Electrical energy measurement and control	Electrical energy measurement and control, for smart metering equipment and systems forming part of smart grids.	WG 11 Electricity metering equipment.; WG 14 Data exchange for meter reading, tariff and load control; WG 15 Smart Metering Functions and Processes
CEN-CLC/JTC 10 Material efficiency aspects for products in scope of Ecodesign legislation	Material efficiency aspects for products in scope of the Ecodesign Directive 2009/125/EC and its future revisions.	WG 5 Ability to recycle and recover energy-related products, recycled material content of energy-related products

Challenges and obstacles

The development and harmonisation of standards in the solar PV sector are crucial to addressing several challenges, particularly those related to the integration of solar technologies into buildings and the installation processes.

A significant concern is the installation of solar panels on building façades, which currently lacks clear guidelines and standards, particularly regarding fire safety. The absence of a standardised fire-test protocol can lead to inconsistent practices across the industry, posing potential risks (VC, Interview 2, 2024). Developing such standards would facilitate the safe deployment of solar technologies and enhance their adoption. As noted by VC (Interview 7, 2024) the absence of standards that bridge the gap between building and PV regulations increases costs and complicates market entry for SMEs. Every modification to integrated PV modules requires retesting, a costly process that could be alleviated through standardised guidelines, particularly in BIPV. Efforts are already underway to address this, with Working Group 9 of ISO/TC 160 discussing the creation of a unified standard merging IEC and ISO frameworks. This initiative focuses on cutting-edge technology, installation requirements, and emerging challenges in BIPV systems (VC, Interview 9, 2024).

Additionally, the absence of standards for the end-of-life management of solar panels remains a critical issue. Standards addressing the weight and size of modules could improve recycling practices and the overall sustainability of the solar industry (VC, Interview 7b, 2024). Developing such standards would support the circular economy by

ensuring that solar panels are designed with their end-of-life in mind, allowing for easier dismantling and recycling. SME involvement in CEN/JTC 10/WG 5, where these matters are discussed, is therefore important.

In conclusion, standardisation is pivotal in addressing the challenges faced by the solar PV industry, from installation to end-of-life management.

Conclusion

SMEs play apivotal in the solar PV value chain, including installation, module production, and, to a lesser extent, cell manufacturing. The EU supportsthem through initiatives like the REPowerEU plan and the EU Solar Energy Strategy.

For SBS, this underscores the importance of actively engaging SMEs in standardisation efforts across the solar PV sector. A key priority should be the standardisation of BIPV technologies. SBS should seek experts to address issues like fire safety and testing methods, enabling participation in ISO/TC 160/WG 9, which is already working on a unified BIPV standard.

As the industry grows, standards for the end-of-life management of solar panels are increasingly urgent. Standards for recycling, module size, and weight are essential for sustainability and to help SMEs navigate the challenges associated with the disposal and material reuse. In this regard, SBS should identity experts to work in CEN-CLC/JTC 10/WG 5 to support the development of end-of-life standards that allow SMEs to access the necessary resources and knowledge to comply with future regulations. This could could be done in collaboration with Solar Power Europe.

Ultimately, SMEs involvement in these standardisation efforts is essential to ensuring they thrive in a competitive and sustainable solar PV market.

2.2 SOLAR THERMAL ENERGY

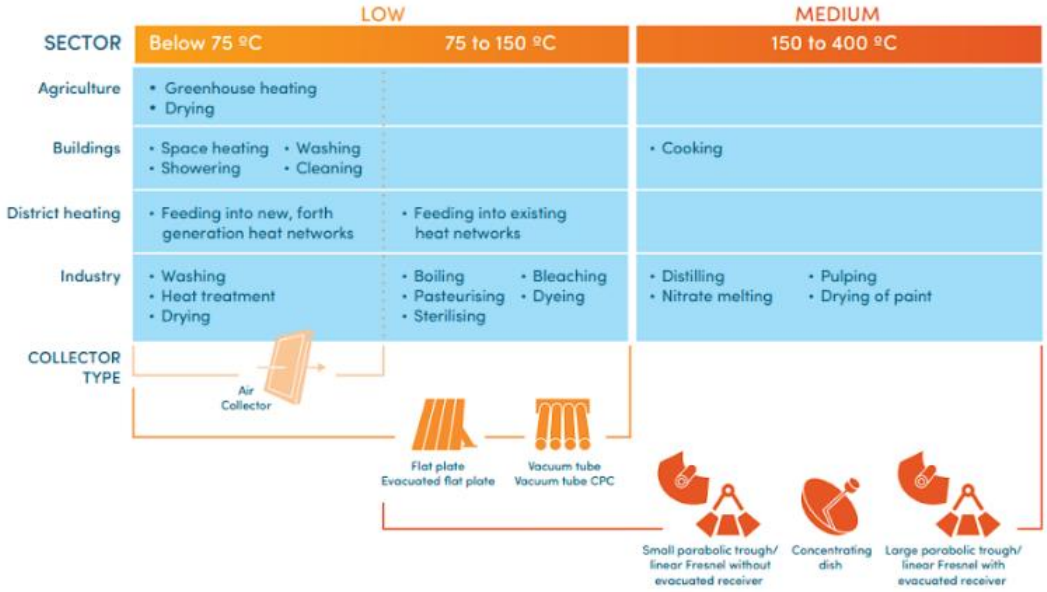
The Solar Thermal Energy and its technologies

The solar thermal industry encompasses several key stages in the production and operation of its systems:

- Raw material extraction: This includes sourcing materials such as glycol, glass, aluminium, polyurethane, rock wool, copper, and stainless steel (Solar Heat Europe, 2022).
- Component manufacturing: The raw materials are then transformed into essential components, including solar energy collectors, heat exchangers, energy storage tanks, and control systems (Karki et al., 2019).
- Utilisation: The thermal energy generated is transferred to specialised pumps or boilers, enabling its effective use in various applications.

Solar collectors are classified based on sun-tracking configuration, collector type, absorber type, concentration ratio, temperature range, and application. These categories are illustrated in **Table 3** and **Figure 3**.

Figure 3 Solar Thermal Value Chain



Source: Solar Heat Europe, 2024

Table 3 Types of Solar Collectors

Sun-tracking configuration	Collector Type	Absorber Type	Concentration Ratio	Indicative Temperature Range
Non-tracking (Stationary)	Air Collector	Flat	1	Below 75
Non-tracking (Stationary)	Flat-plate collector	Flat	1	30-80
	Evacuated tube Collector	Flat	1	50-200
	Compound parabolic collector or Vacuum Tubes	Tubular	1-5	60-240
			5-15	60-300
Single-Axis Tracking	Linear Fresnel reflector or Parabolic trough/linear Fresnel	Tubular	10-40	60-250
	Parabolic trough collector	Tubular	15-45	60-300
	Cylindrical trough collector	Tubular	10-50	60-300
Two-axis Tracking	Parabolic Dish Reflector or Concentrating Dish	Point	100-1000	100-500
	Heliostat Field Collector	Point	100-1500	150-2000

Source: Karki et al., 2019; Solar Heat Europe, 2024

SMEs in the Solar Thermal Energy

SMEs play a significant role in the solar thermal sector, with hundreds actively producing solar thermal panels, storage equipment, and developing projects for solar thermal systems across Europe (Solar Heat Europe, 2024).

Conventional solar water systems, like flat-plate or evacuated tube collectors, are primarily used in residential applications. These systems can also be installed on industrial rooftops to meet heat demand up to 125°C (Irena, 2015). Most solar water heating systems are manufactured locally by SMEs, although there are a few bigger companies (i.e., GreenOneTEC, NVIDIA Thermal) (Irena, 2015; VC, Interview 1, 2024). This technology does not require strong sunglight to produce heat, so installations can be found all over Europe, from Norway to Greece (VC, Interview 1, 2024).

On the other hand, solar air collectors are found primarily in the food processing industry, where they replace gas- or oil-based drying or to reduce food spoilage due to open-air drying (Irena, 2015). They can be constructed locally, with costs varying based on the availability of local building materials and labour (Irena, 2015), providing opportunities for SMEs. However, these businesses are primarily concentrated in Asia (VC, Interview 1, 2024), meaning they are less relevant to SBS.

Thirdly, solar concentrators require direct sunlight which is mainly available in countries such as Spain, Italy, Portugal, Cyprus and Greece in Europe (VC, Interview 1, 2024). This type of technology is more common in India, Turkey, and the Middle East, where the climate is very hot (Irena, 2015).

In terms of use, SMEs are involved in the production and installation of boilers that run on solar thermal energy (VC, Interview 1, 2024).

In conclusion, SMEs in Europe's solar thermal industry are mainly involved as manufacturers, system suppliers, and operators.

EU Policy and legislation related to Solar Thermal Energy

The solar heat industry does not have clear legislated targets set by the European Commission, unlike for Solar PV, but it is included within the renewable energy targets outlined in the Renewable Energies Directive (RED), which aims for a 42% share of renewable energy by 2030. Meeting this target would require almost doubling the existing share of renewable energy in the EU. Additionally, the Net-Zero Industry Act sets a goal for the EU to produce at least 40% of its net-zero technology needs by 2030, reducing reliance on imports and strengthening supply chains of solar thermal energy (EurObserv'ER, 2023).

In Europe, most countries experiencing growth in the solar heat business benefit from national subsidies and support frameworks, underscoring the significant impact of policies and financial instruments in the deployment of renewable solutions (Sutu, 2023).

In 2022, Germany had a record year for solar heating networks, installing eight new large-scale solar thermal systems, primarily for solar district heating (SDH) in smaller towns and municipalities, with a total collector area of 44,923 m² (Sutu, 2023). SDH is a network providing heat, usually in the form of hot water (Solar Heat Europe, 2023). Denmark leads the SDH market with over 120 operational plants, followed by Germany (51), Sweden (23), Austria (20), Poland and France (8 each) (Sutu, 2023).

Another important segment is large systems for the residential, commercial, and public sectors. European countries such as Greece, France, Switzerland, Austria, Poland, and Spain are among the top ten globally for such systems (Sutu, 2023). These installations are often found in hotels, leisure centres, hospitals, or elderly care facilities (Sutu, 2023).

The legislation related to Solar PV is also relevant to the solar thermal industry, i.e., the Eco-design Directive (Directive 2009/125/EC), the Energy Labelling Regulation (EU) 2017/1369, the EPBD and the recently adopted Eco-design Regulation (EU) 2024/1726 (Euractiv, 2018).

Additionally, the Solar Keymark, a voluntary third-party certification mark for solar thermal products, was developed by the Solar Heat Europe/ESTIF and CEN in close co-operation with leading European test labs and with support from the European Commission (Euractiv, 2018). It is the main quality label for solar thermal products and is widely recognised across the European market and beyond.

Standardisation work on Solar Thermal Energy

The section presents the TCs and WGs that are relevant to SMEs in the solar thermal sector, firstly those that are directly related to the industry (see **Table 4**), then those that are indirectly related (see **Table 5**). The blue lines represent TCs where SBS is active.

Table 4 Technical Committees on Solar Thermal Energy

Direct TCs	**Scope**	**WGs**
CEN/TC 312 'Thermal solar systems and components'	Terminology, general requirements, characteristics, test methods, conformity evaluation and labelling of thermal solar systems and components.	WG 1-- Solar collectors WG 3 -- Solar thermal systems
IEC/TC 117 Solar thermal electric plants	Systems of Solar Thermal Electric (STE) plants for the conversion of solar thermal energy into electrical energy and for all the elements in the entire STE energy system.	There are no WGs but only Project Teams and Maintenance Teams. This TC has a liaison and cooperates with ISO/TC 180 (VC, Interview 13, 2024).
ISO/TC 180 Solar energy	Solar energy utilisation in space and water heating, cooling, industrial process heating and air conditioning. This includes standards on the instrumentation and procedures used for measuring solar energy and solar measurement.	AhG 1 Measurement of CO2; WG 3 Collector components and materials; WG 4 Solar collectors SC-1 Climate - Measurement and data SC 4 Systems - Thermal performance, reliability and durability

Table 5 Technical Committees with related work to Solar Thermal Energy

Indirect TCs	**Scope**	**WGs**
CEN/TC 228 Heating systems in buildings	Heating systems, including domestic hot water production, water-based cooling emission and distribution systems in buildings and power generation systems in the direct environment of the building.	WG 1 - General performance requirements of heating systems and sub-systems in buildings; WG 2 Installation and commissioning; WG 3 Instructions for operation, maintenance and use; WG 4 Calculation methods and system performance and evaluation; WG 5 Heating Systems in Buildings
ISO/TC 207 Environmental management	Environmental and climate impacts, including related social and economic aspects, in support of sustainable development.	SC 5 Life cycle assessment **(SBS is present in SC 1 but not in SC 5)**

Notes:

The chair of ISO/TC 180 has provided SBS with guidance on the most relevant working group for SMEs. Within ISO/TC 180, WG 4 is crucial for SMEs engaged in producing solar thermal collectors (VC, Interview 13, 2024). The ISO 9806 standard, developed under this group, is a cornerstone for product validation and is essential for entering and succeeding in the solar thermal market (VC, Interview 13, 2024). Despite the technical complexity of the standard, resources such as the guide produced by the Fraunhofer Institute offer practical explanations that simplify its application, enabling SMEs to achieve compliance effectively (VC, Interview 13, 2024).

Another relevant area within ISO/TC 180 is the subcommittee on climate measurement and data, including the ad hoc group on CO2 measurement (VC, Interview 13, 2024). This initiative aligns with broader sustainability goals, such as reducing carbon footprints and promoting recyclability in solar thermal technologies (VC, Interview 13, 2024). While these efforts are theoretically appealing for SMEs aiming to position themselves as leaders in sustainability, their practical relevance remains limited (VC, Interview 13, 2024). Currently, the market lacks mechanisms to reward sustainable practices, and many SMEs face financial constraints that discourage investment in long-term initiatives without clear short-term returns (VC, Interview 13, 2024). Nonetheless, companies with the vision and resources to invest in these areas can differentiate themselves in an increasingly eco-conscious market. By contributing to the development of such standards, SMEs can help define industry benchmarks and create unique selling points, particularly if they target markets sensitive to sustainability concerns (VC, Interview 13, 2024).

Challenges and Obstacles

The solar thermal energy industry faces several challenges which to a certain extent relate to standardisation. A key issue is the lack of widespread awareness about the economic and efficiency advantages of solar thermal systems over solar PV. According to VC, Interviewee 1, 2024, “When you mention solar, 9 out of 10 people immediately think of PV,” even though solar thermal systems can achieve efficiencies of up to 75%, compared to around 20-21% for PV panels. This awareness gap is partly due to the longer presence of PV technology in the market, and a stronger push from the European institutions, partly overshadowing solar thermal energy.

Standardisation plays a pivotal role in supporting the solar thermal industry. These standards are central to the Solar Keymark, a European quality assurance mark (VC, Interviewee 1, 2024; Euractiv, 2018). This certification mark is tied to European standards

and public funding and ensures that most solar thermal collectors sold in Europe are locally produced, thereby protecting the market (VC, Interviewee 1, 2024).

Despite the robustness of existing standardisation work, the industry faces structural challenges (VC, Interviewee 1, 2024). Solar thermal is primarily composed of SMEs that depend on inconsistent state or EU funding (VC, Interviewee 1, 2024). Variations in subsidy schemes across Europe complicate market stability, with some countries tailoring their subsidy schemes to other technologies, like heat pumps (VC, Interviewee 1, 2024).

SMEs in the solar thermal sector often struggle to navigate the intricate landscape of market intelligence and standardisation (VC, Interview 13, 2024). For example, when SMEs develop disruptive technologies with functionalities not covered by existing standards, they face additional barriers to market entry (VC, Interview 13, 2024). In this context, the Fraunhofer Institute for Solar Energy Systems plays an important role advising SMEs on which standards to comply with and how to align their innovations with these standards to ensure sucessful market entry (VC, Interview 13, 2024). One such innovation is Photovoltaic-Thermal (PVT) technology, a disruptive solar technology that generates both renewable heat and electricity. PVT technology requires standardisation to avoid low-quality products invading the market (VC, Interview 13, 2024). SBS could perhaps collaborate with the Fraunhofer Institute to educate SMEs in the solar thermal sector on standardisation in a user-friendly manner.

Another challenge is establishing consumer trust, a fundamental hurdle for SMEs bringing new products to the market (VC, Interview 13, 2024). Standards play a crucial role in establishing performance benchmarks and quality assurance, thereby fostering trust among consumers and industry stakeholders (VC, Interview 13, 2024). SBS can further this objective by advocating for standards that focus on performance outcomes rather than prescriptive material specifications (VC, Interview 13, 2024). This approach would allow for greater innovation while maintaining quality assurance.

The standardisation challenges faced by the solar thermal industry present both obstacles and opportunities for SMEs. Through strategic support in resource pooling, global standard alignment, and advocacy for innovation-friendly standards, SBS can play a pivotal role in empowering SMEs to navigate these complexities effectively.

Conclusion

The solar thermal energy industry, characterised by strong SME involvement and high-efficiency potential, occupies a unique position within Europe's renewable energy landscape in which SBS could play a pivotal role.

Firstly, SBS should prioritise initiatives that enhance the visibility and perceived value of solar thermal energy. For instance, it could collaborate with stakeholders like Solar Heat Europe and leverage the CEN Solar Keymark certification to promote the advantages of this energy in both residential and industrial applications. This would distinguish it from solar PV and ease the standardisation efforts of SMEs involved in the sector. Additionally, SBS could engage with other organisations, i.e. Fraunhofer Institute and the International Energy Agency Solar Heating and Cooling Program (IEA SHCP) to make SMEs aware and support their involvement in the early stages of standards development.

Secondly, SBS should try to find experts in fields related to CEN/TC 312 WG1 and ISO/TC 180 WG 4 to ensure SMEs are represented in standardisation of solar collectors. It is also crucial that SMEs are informed about essential standards such as ISO 9806, which are critical for market entry (VC, Interview 13, 2024). This engagement should extend to related committees, such as those addressing heating systems and building performance, like CEN/TC 109 and CEN/TC 228.

Lastly, SBS can play a pivotal role in driving innovation and cross-border collaboration among SMEs. Encouraging partnerships between SMEs in high-growth markets like Germany and Denmark and emerging players in less mature markets can help disseminate best practices and technological advancements. By facilitating forums for knowledge exchange and capacity building, SBS can empower SMEs to navigate the complex landscape of standardisation.

In conclusion, SBS should concentrate its efforts on bridging the awareness gap surrounding solar thermal energy, deepening engagement with standardisation bodies, and fostering collaboration among SMEs.

2.3 HYDROPOWER ENERGY

The Hydropower Technology and its Key Technologies

The hydropower industry encompasses several classifications based on water management and head height:

- Run-of-river systems: Operate without large reservoirs and rely on natural water flow, suitable for rivers or cascades (Kleinwasserkraft Österreich, 2024a).
- Storage plants: Use large reservoirs to regulate water flow and power output, allowing flexibility during low-flow or peak demand periods (Kleinwasserkraft Österreich, 2024).
- Head-height systems: High-head installations (above 50 meters) utilise Pelton or Francis turbines, while low-head installations (below 15 meters) rely on Kaplan or Francis turbines (US Department of Energy, 2024).

The turbine selection and operation depend on the criteria from above:

- Impulse turbines: Examples include Pelton and Turgo, which are optimised for high-head and high-pressure water jets (Corà, 2020).
- Reaction turbines: Such as Francis and Kaplan, handle a mix of pressure and flow, making them versatile for different head heights (Kleinwasserkraft Österreich, 2024b).
- Pumps as Turbines (PATs): Used in smaller projects for cost-effective power generation by operating standard pumps in reverse (Corà, 2020).

Finally, protective mechanisms, such as floating booms and trash racks, prevent debris from entering the system, ensuring turbine safety (Corà, 2020). Intake and spillway gates regulate water flow, while penstocks and hydraulic turbine inlet valves control pressure and flow to maintain efficient and safe operations (Corà, 2020).

These elements collectively ensure the efficient harnessing of water's energy to generate and distribute electricity while maintaining system safety and adaptability.

Presence of SMEs in the Hydropower Energy

As of 2016, nearly 22,000 SHP plants were operational, with the highest numbers in Germany (7,100), Italy (4,186), and Austria (3,262) (VC, Interview 3, 2024). Italy leads in

installed SHP capacity (3,568 MW) and electricity generation (11,739 GWh), followed by France, Spain, and Germany. Countries with strong water streams include Austria, Italy, Luxembourg, and Portugal, while Denmark, Estonia, and Hungary have lower Stream Energy. Hydropower remains underdeveloped in Cyprus and Malta (VC, Interview 3, 2024).

SMEs play a significant role in the small hydropower plant (SHP) segment, which accounts for around 8% of Europe's energy mix (European Renewable Energies Federation, 2023). SHPs - defined as those with an installed capacity of 10 MW or less - are often operated by SMEs due to their lower investment requirements compared to larger plants (VC, Interview 3, 2024). Their involvement includes the construction, installation, maintenance, and manufacturing of SHPs, with a particular focus on the operation and maintenance of run-of-river SHPs, given their minimal water requirements (VC, Interview 5, 2024; VC, Interview 4, 2024). Additionally, SMEs often supply and provide maintenance services for turbines, including Kaplan, Pelton, Francis, crossflow, and Archimedean screws, tailoring their offerings to the geographical and hydrological characteristics of the region (VC, Interview 4, 2024).

In countries such as Lithuania, SMEs dominate the renewable energy sector, with small-scale operators and electricity suppliers making a significant contribution to hydropower (IEA, 2022b). Similarly, in nations with more extensive hydropower industries - such as Norway, Austria, and Sweden - SMEs act as local contractors supporting large enterprises, particularly in the development and maintenance of SHPs (IEA, 2021; IEA, 2021b; NorHydro, 2024; Småkraft AS, 2024).

As many older SHPs in Europe require refurbishment, SMEs have opportunities to offer modernisation solutions, enhancing system efficiency and functionality (VC, Interview 5, 2024).

In conclusion, SMEs play a crucial and multifaceted role in the hydropower sector, particularly in the SHP segment.

EU Policy and legislation related to Hydropower Energy

At the EU level, several key legislations and policies impact the SME hydropower industry, including Natura 2000, the Water Framework Directive (WFD) 2000/60/EC and the Strategic Environmental Assessment Directive.[15] Hydropower energy is also covered

[15] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive) [2000] OJ L327/1.; Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (SEA Directive) [2001] OJ L197/30.

by the RED EU/2023/2413, which sets a binding renewable target of at least 42.5% by 2030 and enters into force in all EU countries on 21 May 2025.[16]

Natura 2000 is a network of protected areas covering Europe's most valuable and threatened species and habitats, designated under the Birds and the Habitats Directives (European Environment Agency, 2023). It is relevant for hydropower plant energy suppliers, as projects must consider the surrounding fauna and flora when developing new installations.

The Water Framework Directive establishes a legal framework for the protection and management of all EU water bodies. It required Member States to set up River Basin Management Plans by 2009 to protect and, where necessary, restore the good chemical and good ecological status of water bodies.[17] Hydropower projects must comply with these requirements to mitigate their impact on river ecosystems and avoid altering natural watercourses.

The Strategic Environmental Assessment Directive protects the environment and promotes sustainable development by requiring Member States to carry out environmental assessments for projects likely to have significant environmental impacts, including hydropower plants.[18] This ensures that potential environmental risks are assessed before project implementation.

Standardisation plays a key role in the hydropower sector. Hydraulic turbines, which are highly standardised products, fall under the Ecodesign Regulation[19] and the Energy Label Regulation (EU) 2017/1369[20], as "energy-related products" due to their impact on energy efficiency within hydropower systems. Standards provide methods for testing and verification ensuring turbines meet strict energy efficiency, sustainability, and reliability criteria.

[16] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 [2023] OJ L 282/65, Art.3 (1); Art. 5

[17] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive) [2000] OJ L327/1, Art. 4

[18] Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (SEA Directive) [2001] OJ L197/30, Art 1 & 3(1).

[19] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of Ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC, Art.1 (1); Art. 2. (4)

[20] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU, Art. 1(1), Art. 2(1)

Standardisation work on the Hydropower Energy

The section presents the TCs and WGs that are relevant to SMEs in the hydropower sector, firstly those that are directly related to the industry (see **Table 6**), then those that are indirectly related (see **Table 7**). The blue lines represent TCs where SBS is active.

Table 6 Technical Committees for Hydropower Energy

Direct TCs	**Scope**	**WGs**
IEC/TC 4 Hydraulic turbines	Hydraulic rotating machinery and associated equipment allied with hydro-power development.	WG 14 Hydroelectric Power Plant Automation and Turbine Governing Systems; WG 18 Hydraulic machines, radial and axial Methodology for performance transposition from Model to Prototype; WG 25 Hydraulic machines – Small hydraulic turbines; WG 30 Guide for Installation procedures of hydropower machines; WG 33 Preparation of IEC 62882/Ed1; WG 35 Hydraulic turbines - Scale Effects to Pelton type; WG 36 Calculation of hydraulic transients in hydropower turbine-generator units ; WG 37 Hydraulic machines - IEC 63230 - Fatigue assessment of hydraulic turbine runners: from design to quality assurance; WG 38 Mechanical vibration - Measurement and evaluation of machine vibration; WG 40 Technical Specifications for Digitalisation of Operation and Maintenance in Hydropower Assets; WG 41 Technical Specification for Black Start of Hydropower Plant
ISO/TC 339 SHP plants	Site selection planning, design, construction and management for SHP plants development up to 30 MW.	The TC was created in 2022. According to its business plan adopted in September 2023 the TC aims to created WGs on Terms and definitions; Site selection planning; Design; Construction and Management*

* Note: ISO developed an International Workshop agreement (IWA 33) in 3 parts providing Technical guidelines for the development of small hydropower plants that is at the basis of this new Technical Committee (IWA 33-1:2019, IWA 33-2:2019, IWA 33-3:2021)

Table 7 Technical Committees with related work to Hydropower Energy

Indirect TCs	**Scope**	**WGs**
CLC/TC 57 Power systems management and associated information exchange	Power systems management comprises control within control centres, substations and individual pieces of primary.	WG 18 Hydroelectric power plants - Communication for monitoring and control WG 21-Interfaces and protocol profiles relevant to systems connected to the electrical grid
ISO/TC 207 Environmental management	Environmental and climate impacts, including related social and economic aspects, in support of sustainable development.	SC 5 Life cycle assessment **(SBS is present in SC 1 but not in SC 5)**
CEN-CLC/JTC 10 Material efficiency aspects for products in scope of Ecodesign legislation	Material efficiency aspects for products in scope of the Ecodesign Directive 2009/125/EC and its future revisions.	WG 5 Ability to recycle and recover energy-related products, recycled material content of energy-related products.

Challenges and Obstacles

Hydropower development is heavily impacted by different challenges, which affect both small and large-scale projects. One critical issue is the complexity and cost of the permitting process for SMEs (VC, Interview 3, 2024; VC, Interview 4, 2024). Obtaining permits for new hydropower plants requires navigating an intricate regulatory landscape, involving compliance with environmental, construction, and regional energy legislation. In regions such as Iberia and Slovenia, this process can take up to 12 years, significantly delaying projects and imposing additional financial strains on SMEs, who often face difficulties securing bank loans until permits are finalised (VC, Interview 3, 2024). SBS could advocate for the development of a common European legislative framework aligned with current European standards to create a consensus between countries and simplify permit processes.

The fragmented nature of regulatory frameworks further complicates the development of SHP projects (VC, Interview 4, 2024). In Austria, for example, nature conservation laws differ across its nine federal states, frequently exceeding the requirements of the EU WFD (VC, Interview 4, 2024). These regulatory discrepancies create a patchwork of regulations, making it difficult to standardise processes and obtain necessary approvals, especially where local authorities prioritise environmental conservation over hydropower expansion (VC, Interview 4, 2024; Casey, 2021; Fuergy, 2019). Additionally, increased reporting obligations imposed by both European and national legislation add to the regulatory burden, diverting resources away from operational efficiency and innovation.

Efforts to address these challenges include initiatives such as the SHP Technical Guidelines and Service Package, which aim to standardise practices in project design, operation, and environmental management (VC, Interview 5, 2024). These tools provide SMEs with a framework for meeting international standards and improving competitiveness. Organisations such as UNIDO (United Nations Industrial Development Organisation) offer training programs to enhance national capacity and support the implementation of these standards, ensuring local businesses can participate effectively in the hydropower sector (VC, Interview 5, 2024). However, the continued fragmentation of regulatory frameworks remains a major obstacle to the competitiveness of SMEs.

Conclusion

In conclusion, hydropower represents a cornerstone for regional energy grids, with SMEs playing a pivotal role in the small hydropower (SHP) sector, particularly in Europe. SMEs contribute through operational and technological expertise, and the maintenance of small-scale hydropower plants, often forming essential partnerships within the hydropower value chain. The competitiveness of these SMEs in the hydropower sector remains contingent on broader, coordinated actions to reduce administrative and regulatory burdens, harmonise technical guidelines, and strengthen support mechanisms for SMEs.

It is essential to advocate for streamlined permitting processes at both national and EU levels, emphasising the need for consistency across jurisdictions to reduce delays and financial strains. SBS could collaborate with the European Renewable Energy Federation and support the involvement of European SMEs in ISO/TC 339, which specialises in SHPs, with the aim of developing standards that enhance competitiveness and drive innovation among European SMEs in this sector.

2.4 WIND ENERGY

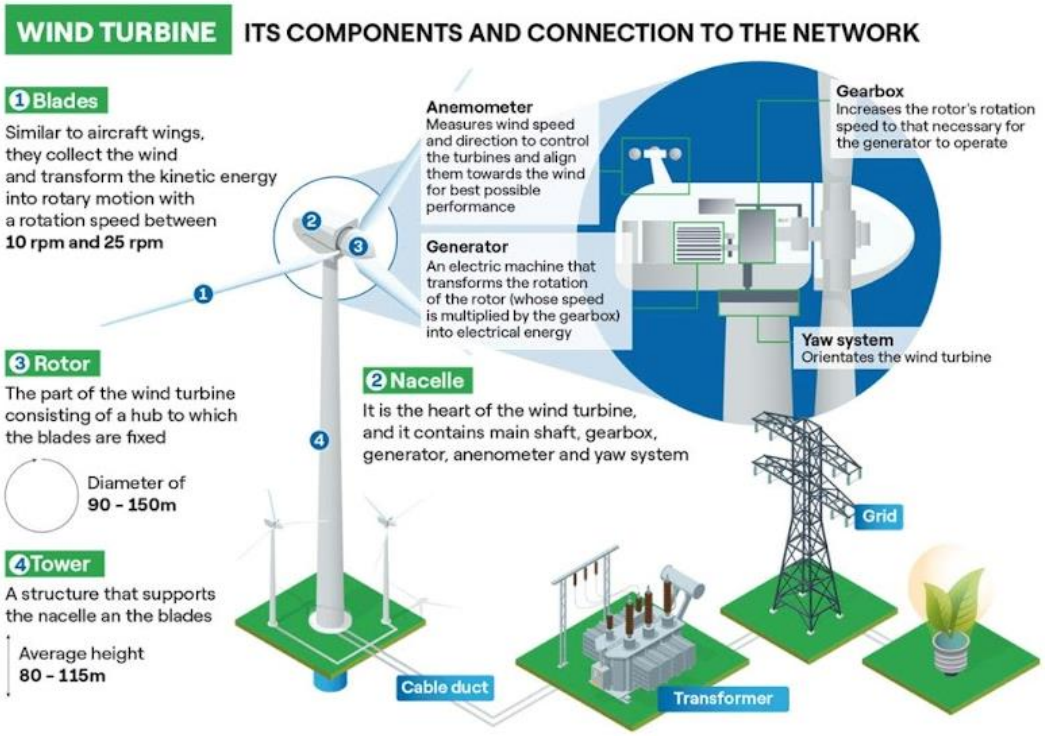
Wind Energy and its Key Technologies

The key components of a wind turbine include (see

Figure *4*):

- The foundation, typically a large concrete structure embedded in the ground, supports the entire turbine and withstands various forces (Enel, 2024; Hernandez-Estrada et al., 2021). For offshore turbines, the foundation is located underwater (Enel, 2024; Hernandez-Estrada et al., 2021).
- The tower, usually constructed of steel but sometimes wood for environmental reasons, is generally composed of three sections assembled on-site (Enel, 2024; Hernandez-Estrada et al., 2021). Its height typically matches the diameter of the rotor's circular path. Inside the tower, power cables connect the nacelle to the ground-level transformer (Enel, 2024; Hernandez-Estrada et al., 2021).
- The nacelle, situated atop the tower, can rotate 360° to align with the wind direction (Enel, 2024; Hernandez-Estrada et al., 2021). Named after the compartment on an aeroplane wing housing jet engine, the nacelle contains critical mechanical components such as the gearbox and generator (Hernandez-Estrada et al., 2021).
- Rotors, the part of the wind turbine consisting of a hub to which the blades are fixed. Two-blade rotors are less expensive and rotate more quickly than those with three blades, but they tend to be noisier and vibrate more (Enel, 2024).
- The hub, which connects the blades to the mechanical parts inside the nacelle, serves as the central point of rotation.
- The blades themselves, typically averaging 52 meters (170 feet) in length, harness the wind's aerodynamic forces (Enel, 2024). Wind causes a pressure differential across the blade surfaces, generating lift and drag; when lift exceeds drag, the rotor spins (Enel, 2024).

Figure 4 The Wind Turbine Components



Source: Enel, 2024 https://youtu.be/zM4E7T8NlnM

There are two primary types of wind turbines: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs) (Enel, 2024; Eriksson et al., 2008; Khudri Johari et al., 2018). HAWTs are the most prevalent and efficient type (Enel, 2024; Eriksson et al., 2008; Khudri Johari et al., 2018). Typically featuring three blades, these turbines operate "upwind," meaning the blades face into the wind and the generator is located at the top of the turbine (Enel, 2024; Eriksson et al., 2008; Khudri Johari et al., 2018).

In contrast, VAWTs feature a vertical rotor shaft and have a design distinctly different from that of the traditional HAWT (Enel, 2024; Eriksson et al., 2008; Khudri Johari et al., 2018). These turbines are omnidirectional, meaning they do not need to be adjusted to face the wind, which is advantageous in locations where wind direction frequently changes (Enel, 2024; Eriksson et al., 2008; Khudri Johari et al., 2018). However, VAWTs are less common due to their reduced efficiency caused by higher air resistance.

SMEs in the Wind Energy

Wind turbines are designed, installed and maintained by highly specialised SMEs and larger, more general enterprises (Cenelec, 2022).

As evidence shows, there is a mix between larger enterprises and SMEs depending on the type of wind turbine, with larger enterprises being slightly more present. One clear indication of this trend is that the European Investment Bank primarily finances large offshore wind projects, which are typically undertaken by major corporations (Rees, 2017). This indicates that smaller enterprises are less involved in these large-scale constructions due to the substantial financial and logistical requirements, which are better suited to large companies.

Despite the dominance of large projects, there is a significant niche for SMEs in the wind energy sector, particularly with smaller-scale wind turbines. These turbines, which range from 0 to 500 kW, are less costly and more accessible for smaller investments (Renewable UK, 2014). In the UK, for example, small and medium wind farms are quite common, with 62% of such installations being owned by farmers and other small-scale operators (Renewable UK, 2014). This trend reflects a growing role for SMEs in the sector, particularly in decentralised and local energy production.

In addition to being energy suppliers, SMEs also play a role in manufacturing small-scale wind turbines. For instance, SD Wind Energy, a company with fewer than 50 employees, is a global leader in the small-scale wind turbine market (Renewable UK, 2014). This indicates that SMEs can thrive as manufacturers of specialised wind energy technologies, complementing their role as energy suppliers.

Another specialised area where SMEs are active is lifting equipment for wind turbines. For example, Fyns Kran Udstyr A/S is a leading SME in this sector (Fyns Kran Udstyr A/S, 2024).

By contrast, the wind turbine rotor blade market is dominated by larger companies and faces significant challenges due to high research and development (R&D) costs (Market Research, 2024). Developing advanced rotor blades that are efficient, durable, and cost-effective requires substantial financial investment (Market Research, 2024). This includes expenses for material research, design optimisation, and testing of prototypes. For instance, the cost of developing new composite materials, which are lighter and stronger than traditional materials, can be prohibitive (Market Research, 2024). These high costs often limit the ability of smaller companies to compete, leading to market consolidation where only financially robust players can afford continuous innovation (Market Research, 2024). Some of the major players in the market include large enterprises like TPI Composites SA, LM Wind Power (a GE Renewable Energy business), Siemens Gamesa Renewable Energy, S.A., Vestas Wind Systems A/S, and Enercon GmbH (Mordor Intelligence Private Limited, 2024). It is important to note that this analysis of the rotor blade market is based on industry reports rather than academic literature, meaning the information may not be entirely reliable.

While enhancing efficiencies in waste collection and combining waste volumes can aid in scaling up recycling efforts, high investment costs and significant energy

requirements often limit the broader implementation of novel composite recycling technologies (Schmid et al., 2020). Consequently, wind turbine blade recycling remains primarily undertaken by large companies, such as LM Wind Power (2024).

In conclusion, SMEs are particularly active in small-scale wind turbine operations and in highly specialised technological niches within the wind energy sector.

EU Policy and legislation related to Wind Energy

The EU prioritises wind energy as a key component of its renewable energy strategy (European Commission, 2023). It aims to meet ambitious 2030 targets by doubling annual wind deployment to 31 GW and achieving over 500 GW of installed capacity with accompanying reforms such as accelerated permitting procedures, streamlined regulations, and financial support for wind energy projects (Wind Europe, 2023; European Commission, 2023).

Despite these efforts, the European wind industry has recently faced operational challenges (European Commission, 2023). The largest wind turbine manufacturers reported significant operating losses in 2022 (European Commission, 2023). Furthermore, with 16 GW of new wind projects installed in 2022, Europe remains far from the 37 GW/year needed to cost-effectively contribute to the EU 2030 targets (European Commission, 2023). Therefore, the Commission has drafted the European Wind Power Action Plan, outlining 15 different actions that the EU and its Member States need to take, based on the pillars represented in the figure below (see ***Figure 5***).

Figure 5 European Wind Power Action Plan Pillars

The Wind Charter builds on the action plan and constitutes a coordinated effort and a common vision to improve the enabling conditions for the European wind industrial ecosystem. It aims to align and swiftly implement the actions of the Commission, Member States and the wind sector (European Commission, 2024b). The key issue is whether these commitments will be followed through in the coming years.

The varied implementation of the Renewable Energy Directive (RED) by Member States offers some insight into this challenge. Following the entry into force of the Directive, Germany issued a record volume of new permits in 2023, and the repowering rate rose to 34%, the highest in nine years (European Commission, 2023). Almost all Member States are accompanying this regulatory overhaul with permitting reforms included in their Recovery and Resilience Plans (European Commission, 2023). Following Germany, the Netherlands had the second-largest growth in wind energy capacity due to record new offshore wind installations. Sweden ranked third with 1.9 GW of new capacity installed, all onshore (Costanzo & Brindley, 2023).

All the components of the wind turbines fall under the Ecodesign Directive/Regulation[21] and the Energy Labelling Regulation (EU) 2017/1369[22], as "energy-related products" due to their impact on energy efficiency within wind turbine systems.

As mentioned earlier, these regulations are supported by standards, providing methods for testing and verification and ensuring that energy-related products meet strict energy efficiency, sustainability, and reliability criteria. The Directive on Ecodesign explicitly supports alignment of European and international standards, such as ISO 14040[23], which explains the relevance of ISO/TC 207 in the next section.[24]

Standardisation work on Wind Energy

The section presents the TCs and WGs that are relevant to SMEs in the Wind Energy sector, firstly those that are directly related to this area (see

[21] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of Ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC, Art.1 (1); Art. 2. (4)
[22] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU, Art. 1(1), Art. 2(1)
[23] ISO 14040 was developed by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*, in collaboration with CEN/SS S26, *Environmental management*.
[24] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products [2009] OJ L285/10, Recital 33

Table 8), then those that are indirectly related (see **Table 9**). The blue lines represent TCs where SBS is active.

Table 8 Technical Committees related to Wind Energy

Direct TC	Scope	WGs
IEC TC 88 Wind Energy Generation Systems	Wind energy generation systems including wind turbines, wind power plants onshore and offshore and interaction with the electrical system(s) to which energy is supplied.	WG 3 Design requirements for offshore wind turbines; WG 15 Assessment of wind resource, energy yield and site suitability input conditions for wind power plants; WG 21 Measurement and assessment of power quality characteristics of grid-connected wind turbines; WG 26 Availability and reliability for wind turbines and wind turbine plants; WG 27 Wind turbines - Electrical simulation models for wind power generation

Table 9 Technical Committees with related work to Wind energy

Indirect TCs	Scope	WGs
CEN/TC 10 Lifts, escalators and moving walks	Safety rules for the construction and installation: - of lifts and service lifts; - of escalators and passenger conveyors.	WG 11 Lifting appliances for wind turbines **(SBS is present in other TC WGs but not in WG 11)**
ISO/TC 108 Mechanical vibration, shock and condition monitoring	Mechanical vibration and shock and the effects of vibration and shock on humans, machines, vehicles and stationary structures, and of the condition monitoring of machines and structures.	SC 5/WG 16 Condition monitoring and diagnostics of wind turbines
ISO/TC 98 Bases for design of structures	Design of structures irrespective of the material of construction including especially terminology and symbols, load, forces and other actions and limitations of deformations. TCs.	SC 3/WG 2 Wind actions on structures

ISO/TC 207 Environmental management	Environmental and climate impacts, including related social and economic aspects, in support of sustainable development.	SC 5 Life cycle assessment **(SBS is present in SC 1 but not in SC 5)**

Challenges and Obstacles

SMEs face significant challenges in entering the wind energy market. This chapter explores how potential solutions could support SMEs in this sector.

Supply chain disruptions pose a critical challenge for SMEs, particularly due to unpredictable price fluctuations in essential materials like steel, copper, and aluminium (Gailly, 2024). These disruptions have been exacerbated by events such as the COVID-19 pandemic and geopolitical tensions (Gailly, 2024).

Another significant barrier to SME entry is the lack of skilled labour in the wind energy sector (Gailly, 2024; Green Economy, 2024). The UK's wind energy industry suffers from a shortage of technicians, particularly in specialised areas like turbine maintenance (Green Economy, 2024). This shortage not only increases operational costs for SMEs but also delays project timelines, reducing their efficiency and profitability (Gailly, 2024). The issue is even more pronounced in offshore wind projects, where sending technicians to sea requires highly specialised training and equipment, a substantial cost burden for smaller companies (Gailly, 2024). Developing standards for workforce training and certification, tailored to the needs of SMEs, could facilitate access to a larger pool of qualified technicians, reducing operational costs and improving project efficiency.

For SMEs looking to expand in the wind turbine market, inadequate port and grid infrastructure poses a significant challenge. Developing the necessary facilities and upgrading ports to support wind turbine production and maintenance can take years (Green Economy, 2024). The lack of suitable infrastructure increases the risk of project delays or abandonment, further discouraging SMEs from entering the market (Green Economy, 2024). Developing clear standardised infrastructure requirements or ensuring that the existing standards are met could help ensure more equitable access to ports and grid facilities.

Addressing these systemic issues through targeted standardisation efforts would not only support SME growth but also drive innovation and competitiveness within the European wind energy market.

Conclusion

In summary, the wind energy sector offers significant opportunities for both large enterprises and SMEs. While large corporations dominate offshore wind projects and rotor blade development due to substantial financial technical requirements, SMEs find their niche in smaller-scale wind turbines, specialised manufacturing, and ancillary technologies such as lifting equipment.

To further support SMEs in the wind energy sector, SBS could focus on increasing its members' involvement, including EFESME in CEN/TC 10/ WG 11 (Lifting appliances for wind turbines), which is directly linked to lifts, as well as its experts in ISO/TC 207 within SC 5 (Life cycle assessment).

Additionally, there is a need to advocate for policies and funding mechanisms that lower entry barriers for SMEs in large-scale wind projects, promote trainings programmes and enhance grid adaptability.

2.5 GEOTHERMAL ENERGY

The Geothermal Energy and its technologies

Geothermal energy is a type of renewable energy that uses the Earth's natural heat to generate power or electricity (BBC, 2024). Most geothermal power plants are in parts of the world that sit on fault lines between tectonic plates (BBC, 2024). The gaps between the plates allow magma to heat up the water, creating more volcanic activity where the Earth's crust is thinner, which helps create the conditions needed to capture geothermal energy more easily (see Figure 6).

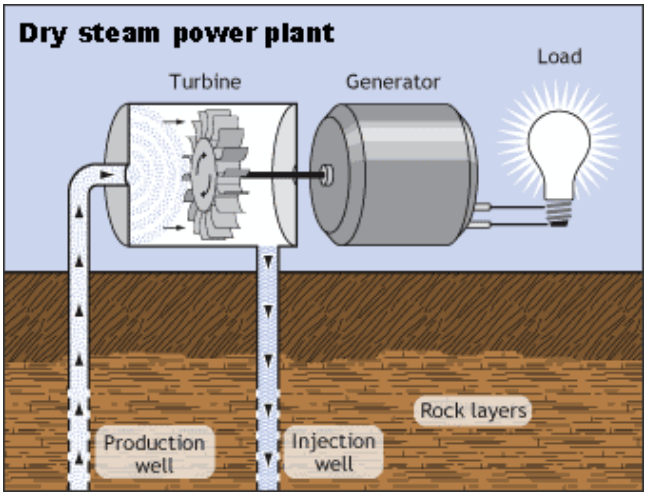
Figure 6 Fault Lines Map

Source: BBC, 2024

The industry can be broadly divided into different subsectors: the subsurface, the surface, the legal and consulting sector (Garabetian, 2019). The subsurface sector involves activities from exploration to well completion (i.e. geothermal well drilling), including reservoir management, accounting for 30 to 50% of the cost of a geothermal project (Garabetian, 2019). The surface industry focuses on constructing equipment above ground. The three main types of surface geothermal technologies are dry steam, flash steam and binary cycle (Dulian, 2023).

Dry steam power plants use high-pressure, high-temperature steam directly from the Earth to turn turbines connected to generators (Dulian, 2023). Wells connect the plant with geothermal reservoirs where the steam naturally rises to the surface and is then routed to the power plant. Direct dry steam plants range in size from 8 to 140MW (Dulian, 2023).

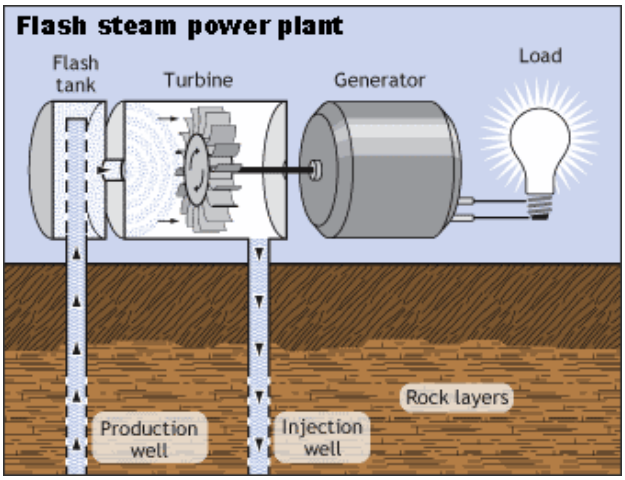
Figure 7 Dry Steam Power Plants Functioning



Source: Gallman (2011)

Flash steam power plants are the most common type of geothermal power plant (Dulian, 2023). They use high-temperature water from geothermal reservoirs to generate power (Dulian, 2023).

Figure 8 Flash Steam Power Plants Functioning

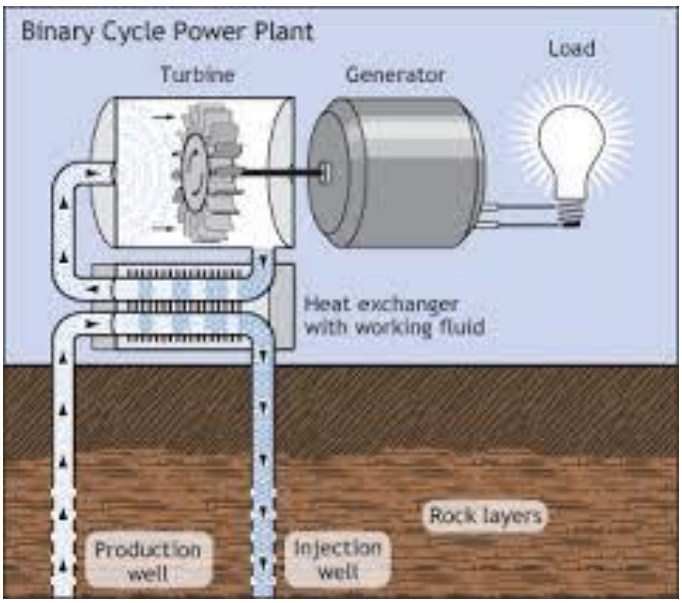


Source: Gallman (2011)

Binary cycle power plants work by using a secondary fluid with a lower boiling point than water contained in a closed loop (Dulian, 2023). The hot geothermal fluid heats this secondary fluid, which evaporates, generating enough pressure to drive a turbine connected to a generator. This technology does not require steam unlike the other two (Garabetian, 2019).

Binary turbines are now the most competitive solution for geothermal electricity in Europe (Garabetian, 2019). They have reached near-market maturity over the past decade, with the binary turbine industry having proven its capacity to scale up manufacturing, and achieve widespread adoption by project developers (Garabetian, 2019).

Figure 9 Binary Cycle Power Plants Functioning



Source: Gallman (2011)

The legal and consulting sectors provide the necessary support to the two aforementioned sectors.

Presence of SMEs in the Geothermal Industry

The geothermal sector comprises a diverse array of SMEs. According to an interview carried out with the European Geothermal Energy Council (EGEC) (see VC, Interview 12, 2024), SMEs are active across the geothermal value chain, but there are some activities where they are more present. Small-sized companies, typically with fewer

than 20 employees, are particularly active in service provision, often comprising engineers specialising in exploration and project support (VC, Interview 12, 2024). In the small-scale drilling sector, companies with as few as five employees dominate (VC, Interview 12, 2024). These firms must excel in pipe management and market expertise, and due to their limited numbers, they are often able to set their own prices, which counterbalances the considerable financial challenges, as investing in drilling rigs—often costing up to €5 million—represents a substantial risk for such small teams (VC, Interview 12, 2024).

In terms of equipment manufacturing, medium-sized enterprises are more prevalent (VC, Interview 12, 2024). These companies generally serve multiple industries and are not exclusively focused on geothermal energy.

For surface installations, such as heat exchangers, pumps, and turbines, large companies primarily dominate, with some medium-sized firms employing 200 to 300 people also active in this space (VC, Interview 12, 2024). When it comes to surface operations and maintenance, larger companies are typically responsible due to the scale and complexity of the tasks involved (VC, Interview 12, 2024).

According to the Geo-Energy Europe project (2024), SMEs in the geothermal industry, represent over 650 geothermal enterprises across Europe, including 362 SMEs from 23 EU countries (Geo-Energy Europe, 2019). The 362 SMEs include: 97 Project Developers and Operators, 78 Geoscience professionals, 50 Drilling experts, 40 professionals in cross-sectional sectors such as IT and communication, 20 specialists in manufacturing surface installations, 18 experts in Production, Maintenance, and Optimisation, 12 professionals in Manufacturing Subsurface equipment, 12 involved in Engineering, Procurement, and Construction, 8 professionals in Health, Safety, and Environment: Ensuring safety and environmental compliance, 7 Power/District Heating Suppliers, 6 in Research, Training, and Education and 2 in Finance, Investment, and Insurance (Geo-Energy Europe, 2019b).

In conclusion, SMEs play a critical role across various sectors in geothermal energy, including service provision, drilling and equipment manufacturing.

EU Policy and legislation related to Geothermal Energy

The Geothermal Implementation Working Group (IWG) is one of the designated WGs supporting the implementation of the SET Plan, Europe's Strategic Energy Technology Plan (Strategic Energy Technology Plan Geothermal IWG, 2023). The IWG

brings together SET Plan countries[25], the geothermal energy industry, and the research community at a European level (Strategic Energy Technology Plan Geothermal IWG, 2023). Its mission is to coordinate research and innovation efforts and jointly support the transition to a resilient and climate-neutral Europe which utilises geothermal energy to its full potential (Strategic Energy Technology Plan Geothermal IWG, 2023).

The IWG envisages a net-zero Europe in 2050, where:

- Geothermal heat supplies more than 25% of Europe's demand for space heating and cooling, and more than 25% in the agricultural sector and 5% in industrial sectors in the low to medium temperature range.
- 10% of the power production in SET Plan countries comes from geothermal power.
- Underground thermal energy storage supplies more than 10% of Europe's demand for space heating, mainly for district heating, thus requiring collective systems.
- Co-production of minerals and critical raw materials (CRM) such as lithium for the resilient transportation sector and strategic autonomy is established in at least 10 European regions.

In line with EU goals on resilience, the IWG aims to increase resilience of the geothermal energy supply chain, and to have 40% of the supply chain "Made in Europe" by 2030. As of now the most competitive market is the Turkish one for its geographical advantage, which offers relatively low barriers to entry (Garabetian, 2019). The equipment market in Turkey is also very competitive, as highlighted by the presence of 8 different turbine manufacturers, including 4 European companies (Exergy, Atlas Copco, Turboden, Ansaldo Tosi) (Garabetian, 2019).

However, Turkey is not the only market in the region. For example, Ireland, Germany and Poland have launched national roadmaps to aid the rapid growth of geothermal in their countries (Dumas, 2024). Belgium, Cyprus, Finland, France, Germany, Iceland, Ireland, Italy, Portugal, The Netherlands, Turkey, Spain, Sweden, and Switzerland are also in the IWG which is driving the geothermal energy forward (EGEC Geothermal, 2024). In conclusion, the EU is driving geothermal energy forward.

[25] The working group for deep geothermal energy is co-chaired by Germany, Italy and the Netherlands and includes Member States and non-EU government representatives: Belgium, Cyprus, Finland, France, Germany, Iceland, Ireland, Italy, Portugal, The Netherlands, Turkey, Spain, Sweden, and Switzerland; – representatives of the European Commission; – the European Geothermal Energy Council (EGEC) – the EERA Joint Programme Geothermal Energy (JPGE) and the European Geothermal ETIP.

Standardisation work on Geothermal Energy

This section presents the TCs and WGs relevant to SMEs in the Geothermal Energy sector.

Table 10 Geothermal Technical Committees

TCs	Scope	WGs
CEN/TC 151 - Construction equipment and building material machines - Safety	Safety of machines and equipment used on construction sites, for winter service and highway maintenance as well as for the production and processing of mineral building materials. In exceptional cases glass machinery used outside the building material sector (e.g. laboratory glass machinery) is included.	WG 3 - Drilling equipment - Safety
CEN/TC 155 - Plastics piping systems and ducting systems	Requirements and test methods for geometrical, chemical, physical and other characteristics of components, joints and systems of the plastics related requirements and test methods for fitness for purpose of complete systems.	WG 23 Thermoplastics systems for industrial applications
CEN/TC 196 - Machines for underground mines - Safety	Standardisation relating to safety aspects of – specialized mining machinery and equipment for opencast mining (e.g. conveyors, high wall miners, rock drill rigs and continuous surface miners).	WG 8 - Rock drill rigs and reinforcement rigs
CEN/TC 262 - Metallic and other inorganic coatings	Metallic and other inorganic coatings, for corrosion protection of metals and for decorative and engineering purposes	WG 10 Corrosion likelihood

Notes:

IEC/TC 5 on steam turbines is not mentioned because it is not very relevant for SMEs in the geothermal sector as steam turbine manufacturing is dominated by large corporations (VC, Interview 12, 2024). While SMEs may contribute components (e.g., bolts, pipes), they are not involved in turbine assembly or large-scale production (VC, Interview 12, 2024). Binary turbines, used in geothermal and other industries like biomass and waste heat, present opportunities for SMEs, but these are not yet significant enough to warrant dedicated standardisation efforts (VC, Interview 12, 2024).

Plastic pipes are used in geothermal installations (The Plastics Pipe Institute, 2023). Plastic pipes are lighter than other materials, making them easier to handle and install. For most common small- and medium-sized pipes, a single person can manage installation. Mechanical lifting is only required for large diameter pipes. Therefore, plastic pipes have lower transport, handling and manpower costs (TEPPFA, 2020). This increases the likelihood of SMEs forming part of the sector.

The rock drilling rigs market is served by various actors, multinational large companies as well as SMEs (Epiroc USA LLC, 2024; Massenza, 2024; VC, Interview12, 2024). Moreover, erosion-corrosion can be a significant issue for engineering components used in the geothermal industry (Brownlie et al., 2021). Many engineering alloys used in the geothermal industry are steel (Brownlie et al., 2021), which is often produced by larger enterprises.

CEN/TC 262/WG 10 and CEN/TC 196/WG 8 have limited relevance for geothermal SMEs, as most safety standards for drilling in the geothermal sector already exist and significantly overlap with those from mining, oil, and gas industries (VC, Interview 12, 2024).

Challenges and obstacles

Geothermal energy is a sustainable and reliable source of power, producing minimal GHG emissions while ensuring constant baseload energy generation (Dulian, 2023).

Despite these advantages, several challenges impede the expansion of large-scale geothermal capacity. A significant barrier to geothermal development is the fragmented nature of statistical data and the inadequacy of geothermal resource mapping (Dulian, 2023; Krasnodębski, 2023). The European Parliament has called for the creation of an EU-level centralised portal for geological data that is standardised, freely available, and user-friendly for all stakeholders (Krasnodębski, 2023). This initiative is ongoing, with the Geological Service for Europe (GSTU) already working towards building a comprehensive European database of geological data (VC, Interview 12, 2024).

VC, Interview 12, 2024 highlighted that while fragmented data remains an issue, efforts to address it also involve Eurostat and national statistical offices under existing regulations.[26] There may be scope to further explore whether new guidelines or

[26] COMMISSION REGULATION (EU) 2022/132 of 28 January 2022 amending Regulation (EC) No 1099/2008 of the European Parliament and of the Council on energy statistics, as regards the implementation of updates for the annual, monthly and short-term monthly energy statistics

improvements to current regulations could facilitate progress. Standards could perhaps also play a role in these developments.

Looking ahead, the industry recognises the absence of standards as a critical challenge (VC, Interview 12, 2024). A consensus among market actors has prompted plans to launch a new working group on industry standards in early 2025 at EGEC (VC, Interview 12, 2024). While specifics are yet to be defined, there is notable interest in topics such as drilling and ethics (VC, Interview 12, 2024). Furthermore, a new standard on deep drilling is expected in April 2024, developed by the International Association of Drilling (VC, Interview 12, 2024). These initiatives are undertaken within industry associations; however there may be opportunities and advantages for them to extend into the development of European (or international) standards under the relevant European or International standards organisations.

On 16 December 2024, the Council of the EU approved conclusions on the promotion of geothermal energy. These conclusions call for a faster deployment of geothermal energy and for the European Commission to prepare a European geothermal action plan and to set up a European Geothermal Alliance (VC, Interview 12, 2024). This platform, bringing together Member States, industry, and the European Commission, aims at addressing key challenges and prioritise standardisation as part of its activities (VC, Interview 12, 2024). These developments underscore a growing momentum within the sector to resolve existing barriers and advance geothermal energy as a sustainable resource.

The variability in national regulatory frameworks further complicates the geothermal sector. Disparities in permitting processes, drilling market conditions, and legal frameworks lead to uneven competition and fragmented markets (Dulian, 2023; Krasnodębski, 2023). For example, the European Parliament has highlighted legal frameworks in some Member States, where project assessment deadlines operate under the "tacit approval" principle. Under this principle, projects may be deemed approved under clearly defined conditions unless a formal response is mandated by either EU or national law. The European Parliament has called on Member States to explore the potential advantages and challenges of applying this principle to geothermal projects and to consider its integration into national legislation (Krasnodębski, 2023).

Public acceptance of geothermal energy poses an additional challenge (Dulian, 2023; Krasnodębski, 2023). Limited public knowledge about geothermal technologies, along with concerns regarding land use, environmental consequences, and potential social impacts contribute to resistance. Strategies to mitigate these challenges and foster market growth include:

(i) leveraging favourable regulatory frameworks and facilitating the interconnection of regional electricity grids to enable the export of geothermal electricity from countries with high geothermal potential;

(ii) enhancing synergies with renewable hydrogen production to alleviate financial constraints; and
(iii) optimising electricity production efficiency from medium-temperature geothermal resources, thus minimising the need for deep drilling, which can introduce higher risks (Dulian, 2023; Krasnodębski, 2023).

In conclusion, while geothermal energy holds immense potential for sustainable energy generation, its growth is hindered by challenges that could be addressed through the development of standards and legislation.

Conclusion

SMEs contribute to the development of the deep geothermal market, shallow geothermal applications, and supporting services such as civil engineering, hydrogeology, and the production of surface and subsurface equipment. Despite their pivotal role, SMEs face challenges such as fragmented resource data, regulatory hurdles, and limited representation in standardisation discussions. The European Commission's Geothermal IWG and the revised Renewable Energy Directive (RED) provide a framework for enhancing geothermal energy's contribution to Europe's energy mix, with a vision for a net zero Europe by 2050. However, these ambitious goals require coordinated efforts from all stakeholders.

SBS could take action to advocate for better access to centralised and standardised geological data, addressing the current barriers caused by fragmented resource mapping and look for ways to cooperate with the Geothermal IWG, EGEC and national geothermal associations in key markets such as Germany and Turkey (e.g., GeoEnergy Celle or Jesder).

On the standardisation front, SBS should work closely with CEN/TC 151/WG 3 - Drilling equipment – Safety. Given the importance of materials such as plastics and steel in geothermal installations, SBS could also collaborate with organisations like the European Plastic Pipes and Fittings Association to ensure cost-effective and sustainable solutions tailored to SMEs.

Lastly, SBS could organise capacity-building workshops and networking events to bridge the gap between SMEs and large enterprises in the geothermal sector, enabling knowledge exchange and fostering partnerships. By focusing on these actions and leveraging collaborations, SBS can help create a more inclusive and competitive geothermal energy landscape in Europe.

2.6 OCEAN ENERGY

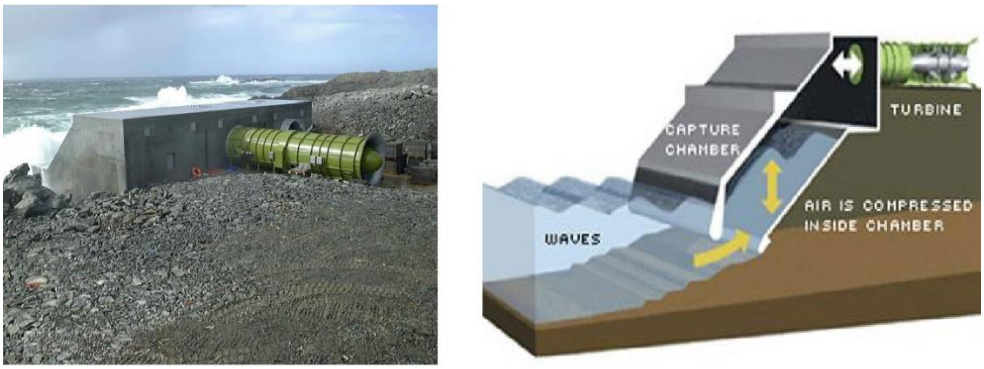
Ocean Energy and its technologies

Ocean currents, tides, and waves can be harnessed to generate electricity (IRENA, 2022). Among the promising ocean energy technologies are several innovative approaches:

1. Wave Energy (IRENA, 2022; Ocean Energy Europe, 2024)

- **Oscillating Water Columns**: Structures that use wave movement to compress and decompress air, driving a turbine to generate electricity (Cuadra et al., 2016; see **Figure 10**).

Figure 10 Oscillating Water Columns

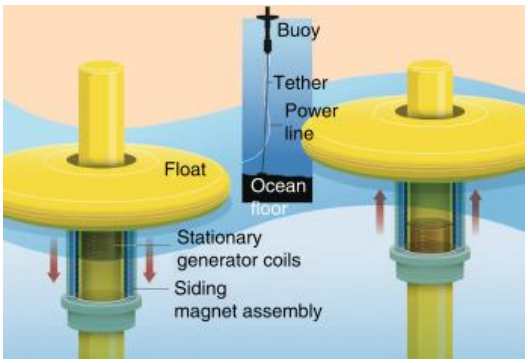


(a) Prototype OWC [20]. (b) Schematic of the OWC [21].

Source: Hasan & Manasseh, 2014

- **Oscillating Body Converters**: Devices that utilise the relative motion between wave-driven components and a fixed point (Guo et al., 2022; see **Figure 11**). Examples include Oscillating Wave Surge Converters (harvest energy from horizontal wave motion using floats, flaps, or membranes) and Point Absorbers (floating buoys that harness energy from wave motion at the water's surface)

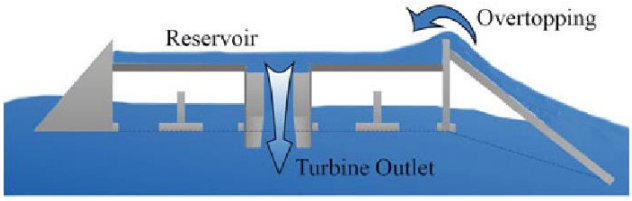
Figure 11 Oscillating body converters



Source: Sang et al., 2018

- **Overtopping Converters**: Devices that convert wave energy into potential energy by channelling water into a reservoir to drive turbines (Ocean Energy Service, 2024; see **Figure 12**).

Figure 12 Overtopping Converters

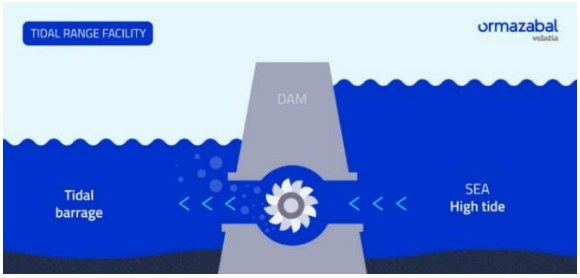


Source: Xie & Zuo, 2013

2. Tidal Energy (Tapoglou et al., 2022; IRENA, 2022)

- **Tidal Range Technologies**: Systems that use barrages (dams or barriers) to generate power from the height difference between high and low tide, employing turbines such as bulb turbines (Kempener & Neumann, 2014; see **Figure 13**).

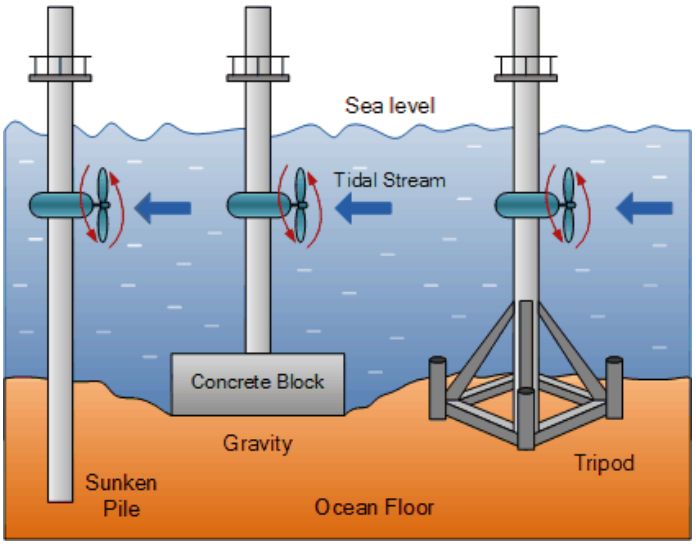
Figure 13 Tidal-range technologies



Source: Ormazabal Velatia, 2023

- **Tidal Current or Tidal Stream Technologies:** Devices placed directly in tidal currents or streams to generate electricity from water flow without requiring a dam structure (see **Figure 14**).

Figure 14 Tidal-current or tidal-stream technologies



Source: Alternative Energy Tutorials, 2024

3. Salinity Gradient Energy (IRENA, 2022)

- **Pressure Retarded Osmosis**: Technology where freshwater flows through a membrane to increase pressure in a saltwater tank, producing energy.
- **Reverse Electro Dialysis:** Systems where ions from salt pass through alternating tanks of saltwater and freshwater to generate electricity.

4. Ocean Thermal Energy Conversion (OTEC) (IRENA, 2022)

Generates power from the temperature difference between warm surface seawater and cold deep seawater at depths of 800–1,000 meters.

Each of these technologies represents a specific approach to harnessing the ocean's energy for electricity generation. The last two types of ocean energy are relatively recent, not yet mature, and will not be further explored in this report (Tapoglou et al., 2022).

Presence of SMEs in the Ocean Energy sector

SMEs play an important role in Europe's Ocean energy industry, though large corporations dominate the sector (The European Commission, 2020; Ocean Energy Europe, 2023). SMEs account for 37.6% of private for-profit entities involved in EU-funded ocean energy projects, showcasing their active contribution to innovation and development under programmes like FP7 and Horizon 2020 (Tapoglou et al., 2022). This information is particularly relevant because most ocean energy farm operators often reoly on fundings to remain viable (Ocean Energy Europe, 2022).

Wave energy presents varied opportunities for SMEs (VC, Interview 14, 2025). A notable example is CorPower Europe, a medium-sized enterprise of 85 employees designing, manufacturing and operating wave energy farms since 2012 (Alonso Viña, 2024). The company aims to become a leader in harnessing wave motion for energy generation and to establish this sector as a viable alternative to wind and solar power (Alonso Viña, 2024). CorPower is considered as a high-potential startup attracting significant interest in Europe (Alonso Viña, 2024). Nevertheless, the company has decided to open an office in the United States, where access to funding is easier (Alonso Viña, 2024). "The problem in Europe is that we are spreading small amounts of money across many initiatives, rather than focusing it where we could truly become global leaders," laments the co-founder of the company. The sector estimates it needs €1 billion to scale this technology, but the European Union's response has been modest (Alonso Viña, 2024). They have allocated two €90 million funds for the sector, and that's great. But it's not enough. Other European SMEs contributing to the sector are HydroQuest, Schottel, CalWave Inc. and Symphony Waterpower, all of which are members of Ocean Energy Europe, a non-profit organisation representing the sector. Among the above-mentioned technologies, Oscillating Water Columns are the most accessible due to their maturity, reliability, and relative ease of market entry (Ocean Energy Office, 2013; Seo et al., 2022). Conversely, Oscillating Body Converters and Overtopping Converters are less accessible, as these technologies remain immature or require significant investment, limiting SME involvement (Guo, 2022; Christensen et al., 2005).

In tidal energy, Tidal Stream Energy presents opportunities for SMEs, particularly in areas such as horizontal-axis tidal stream devices, which have reached high technology readiness levels and are becoming increasingly cost-effective (Catapult Offshore Renewable Energies, 2024; Tapoglou et al., 2022). However, since 2010, market leadership has shifted to large corporations (Kempener & Neumann, 2014). Tidal Range Energy remains largely inaccessible to SMEs due to limited sites, high initial costs, and environmental concerns, restricting this segment to large-scale enterprises (Tapoglou et al., 2022).

In summary, SMEs are more likely to participate in wave energy technologies than in tidal energy technologies.

EU Policy and legislation related to Ocean Energy

The EU has positioned ocean energy as a key priority within the European Energy Union and the European Green Deal to advance its RED targets (Tapoglou et al., 2022). The EU Offshore Renewable Energy Strategy aims to achieve 100 MW of ocean energy by 2025 and 1 GW by 2030 (Ocean Energy Europe, 2023B). Indeed, installed capacity has been increasing across all ocean energy types with Sweden having the largest installed capacity amongst EU countries, followed by France. However, only a limited number of devices have reached commercial readiness, and few ocean energy devices are currently deployed a commercial capacity. The development of the market relies on multiple technological, financial and environmental parameters (Tapoglou et al., 2022).

Financially, the EU has supported companies through public investments, leading the sector globally by contributing 46% of global public investment in the last decade (Tapoglou et al., 2022). The EU has funded ocean energy research and development for many years (European Commission, 2024c). Their focus has been on demonstrating the reliability of ocean technologies and their ability to withstand harsh sea conditions, thereby reducing risk for project developers and investors (European Commission, 2024c). EU support also aims to enhance ocean energy's cost competitiveness compared to other technologies and to demonstrate its market potential (European Commission, 2024c).

In terms of private investments, EU companies are the second-largest investors in ocean energy, following China. Venture capital investment in the EU is predominantly directed towards later stage funding, accounting for 77% and 74% of the total investment during the periods 2010-2015 and 2016-2021, respectively (Tapoglou et al., 2022). The availability of financial resources in the EU has led to an greater number of high-value patents compared to global competitors, with 34% of high-value inventions originating from the EU. To establish ocean energy as a key energy source, further investments will be necessary (Tapoglou et al., 2022).

The EU is highly competitive in the ocean energy sector, with 41% of tidal stream developers with a Technology Readiness Level (TRL) above five based in the EU (Tapoglou et al., 2022). Similarly, the majority (52%) of companies developing wave energy devices are located in the EU. The EU also leads in the number of scientific publications on wave energy and ranks second in tidal energy research, closely following

the UK. Table 17 presents the major strengths, weaknesses, opportunities and threats of ocean energy technologies (Tapoglou et al., 2022).

With continued investment, technological advancements, and a globally competitive position, the EU has the potential to establish ocean energy as a more mainstream renewable source, contributing decisively to a sustainable energy future.

Regarding standardisation, steam turbines fall under the Ecodesign Regulation[27] and the Energy Label Regulation (EU) 2017/1369[28], as "energy-related products" due to their impact on energy efficiency within the geothermal power plant.

As mentioned before, these regulations are supported by European standards, providing energy efficiency measurements, sustainability, and reliability criteria and methods for testing and verification.

Standardisation work on Ocean Energy

The section presents the TCs and WGs that are relevant to SMEs in the Ocean Energy sector, firstly those that are directly related to industry (see **Table 11**), then those that are indirectly related (see **Table 12**).

Table 11 Ocean Energy Technical Committees

Direct TCs	Scope	WGs
IEC TC 114 Marine energy - Wave, tidal and other water current converters	To prepare international standards for marine energy conversion systems.The primary focus is on conversion of wave, tidal and other water current energy into electrical energy, although other conversion methods, systems and products are included. Tidal barrage and dam installations, covered by IEC/TC 4, are excluded.	Only Project Teams, Maintenance Teams, Advisory Groups. The TC is still relevant for SMEs in this field (VC, Interview 14, 2025)

[27] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC, Art.1 (1); Art. 2. (4)

[28] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU, Art. 1(1), Art. 2(1)

Table 12 Technical Committees with related work to Ocean Energy

Indirect TCs	Scope	WGs
CEN/TC 230 Water analysis	Water analysis including: - definition of terms; - sampling of water; - measurement; - reporting.	WG 1 Physical and biochemical methods; WG 2 Biological methods co-ordination group; WG 21 Invertebrates; WG 23 Aquatic macrophytes and algae; WG 24 Fish monitoring; WG 25 Water body characteristics; WG 26 Quality assurance; WG 27 Marine ecological methods; WG 28 DNA and eDNA methods; WG 4 Performance Requirements for Water Monitoring Equipment

Challenges and obstacles

The ocean energy sector faces several key challenges and obstacles that limit its integration into Europe's energy mix. Although tidal stream and wave energy devices have been tested in European waters over the past decade, only a small number of systems are currently operational (European Commission, 2024c). Significant advances in research, development, demonstration, and validation are still required to unlock the full potential of ocean energy in supporting energy supply, fostering industrial growth, and contributing to climate change mitigation (European Commission, 2024c). Progress is essential across multiple areas, including device design, system integration, logistics, and environmental impact assessments (European Commission, 2024c).

For wave energy, specifically, smaller, more durable, and cost-effective converters need to be developed and tested, especially in low-energy seas such as the Mediterranean and Baltic, where current knowledge remains limited (Foteinis, 2022). Presently, many wave energy technologies are not adapted to the milder wave regimes of these seas, resulting in low-capacity factors, suggesting that further downscaling is necessary for economic feasibility (Foteinis, 2022). High costs present a substantial hurdle, with the Levelised Cost of Electricity (LCoE) currently averaging €0.27/kWh for wave and €0.20/kWh for tidal energy. The EU's Strategic Energy Technology plan aims to reduce these costs by 2030, targeting €0.10/kWh for tidal and €0.15/kWh for wave energy, but achieving this will require scaling up deployments and refining technologies to drive costs down (Tapoglou et al., 2022). VC, Interview 14, 2025 highlighted the challenge faced by smaller organisations due to the lack of existing facilities that could be leveraged for cost-sharing in federally supported development contracts, unlike larger organisations that benefit from facilities established through previous projects. He also noted that the

requirements of government funding awards should be adjusted according to the size, revenue and focus of SMEs (VC, Interview 14, 2025). For technologies intended to be deployed through project financing, comparable to wind and solar technologies, standards are critical to advance them towards insurability and bankability (VC, Interview 14, 2025). The main challenges are costs, project duration and determining at which stage of the development cycle these investments are most impactful given the limited resources of SMEs (VC, Interview 14, 2025).

Additionally, while tidal energy technologies are converging on horizontal-axis devices, wave energy remains fragmented, with various device concepts competing for viability (Tapoglou et al., 2022). These technological and cost challenges also affect the involvement of SMEs, which find it difficult to participate in a sector where initial investments are high, and commercial viability is not yet widespread (European Commission, 2020). As a result, although Europe leads in ocean energy innovation, the high costs and need for technological optimisation continue to hinder its integration and scalability in the European energy system.

Conclusion

Ocean energy holds considerable potential for advancing Europe's renewable energy transition and meeting the ambitious objectives set forth in the European Green Deal. Technologies such as wave energy converters, tidal stream devices, and salinity gradient systems demonstrate notable promise. Nevertheless, the sector remains at an early stage of development, with barriers including technological immaturity, high costs, and unresolved environmental concerns hindering its broader deployment.

Given this context, SBS should focus its efforts on advocating for increased EU funding dedicated to projects led by SMEs. Additionally, SBS should identify experts to foster collaboration with TCs, notably IEC TC 114, to ensure that standardisation efforts align with the needs of SMEs and address existing gaps limiting market access. To further support SMEs, SBS should also champion policies designed to lower entry barriers, including the creation of tailored financial support mechanisms, improved access to testing infrastructure, and the development of platforms for knowledge sharing and capacity building.

2.7 HYDROGEN TECHNOLOGIES

The Hydrogen Industry and its technologies

Hydrogen is a colourless, odourless, non-toxic gas that ignites easily and burns with a pale blue, almost invisible flame. It is lighter than air vapours (Hren et al., 2023). It is considered a high-risk gas because due to its wide flammable and explosive range, requiring only a small amount of energy for ignition (Hren et al., 2023). This, together with very low temperatures required, presents a challenge for the safe handling of hydrogen (Hren et al., 2023).

At present, the most common method of hydrogen production is methane steam reforming, which accounts for around 76% of global hydrogen supply. However, this process relies on fossil fuels and generates greenhouse gas (GHG) emissions (Hren et al., 2023). Nonetheless, there are sustainable alternatives for hydrogen production, which will be further discussed in the next section, as SMEs are more involved in this kind of production.

Presence of SMEs in the Hydrogen Industry

SMEs are increasingly involved in the hydrogen energy sector, from production to distribution, reflecting their pivotal role in the broader transition to sustainable energy sources (European Commission, 2024d; Clean Hydrogen Partnership, 2022; VC, Interview 6, 2024).

Below is an explanation of the main technologies found in the industry by sector and whether SMEs are present: Production/Operation, Storage, Transportation and Utilisation technologies.

A) Hydrogen Production Technologies Relevant to SMEs

There are various methods for producing hydrogen: reforming, by-product, water electrolysis, oxidation of aluminium, and dark fermentation. However, some technologies, particularly those requiring large-scale processes like reforming, are less relevant for SMEs and will be only briefly addressed in this report.

1) Hydrogen Synthesis via the Conversion of Syngas (Reforming)

Reforming accounts for 91% of global hydrogen production (Clean Hydrogen JU, 2023). These reforming technologies convert natural gas and other hydrocarbons into syngas (Hren et al., 2023). This process is highly mature and primarily conducted by large natural gas extractors and chemical companies, requiring significant infrastructure and capital investment (Hren et al., 2023; VC, Interview 8, 2024).

There are other manners of reforming natural gas, such as steam reforming of alcoholic waste and glycerol steam reforming, which show potential but are also capital-intensive and complex (Ismaila et al., 2020; Cortés et al., 2019). While some SMEs are involved in sectors like waste alcohol processing, these technologies are typically not core SME activities.

However, SMEs may be involved in analysing the quality of the hydrogen or providing innovative research and consulting solutions to larger enterprises (VC, Interview 8, 2024).

2) Water Electrolysis for Hydrogen Production

Alkaline electrolysis is a more SME-friendly technology. It is a well-established method of producing hydrogen by splitting water into hydrogen and oxygen using electricity, often generated from renewable resources such as wind or solar power (Hren et al., 2023). This process is carbon-free if powered by renewable energy, making it a key technology in the transition to a sustainable hydrogen economy.

SMEs are well-positioned to adopt electrolysis technology due to its scalability. Unlike large-scale hydrocarbon reforming, which requires extensive infrastructure, electrolysis can be deployed in local, smaller-scale settings (VC, Interview 8, 2024). SMEs can integrate electrolysis into existing renewable energy systems, using excess electricity from wind turbines to produce hydrogen. This hydrogen can be stored, addressing renewable energy surplus challenges (VC, Interview 8, 2024). Thus, SMEs play a crucial role in regional green hydrogen production and storage. Examples of SMEs active in this space include ErreDue and Next Hydrogen (Idrissov, 2024), which focus on developing and improving electrolyser technologies.

3) By-product Hydrogen Production

Hydrogen can also be produced as a by-product in industrial processes, such as chlorine or sodium chlorate manufacturing (Clean Hydrogen JU, 2023). Although this sector is dominater by larger plants, SMEs may participate in niche applications or as component suppliers within these processes.

4) Oxidation of Aluminium for Hydrogen Production

Hydrogen can be produced by combusting aluminium with water. This method is becoming increasingly cost-effective, creating opportunities for SME involvement due to its simplicity and scalability (Kaur & Verma, 2024). Startups such as *Hydropore* are developing systems that use recycled aluminium to generate hydrogen and other by-products.

B) Hydrogen Storage and Transport Options

The second phase of the hydrogen value chain involves storage and transportation, which can occur in various forms.

1) Physical Storage

Hydrogen can be stored as a gas or liquid.

- **Compression — Compressed Hydrogen Gas through Pipelines or Lorries**

Compressed hydrogen (CH2) is stored at high pressures (150–700 bar) in a gaseous state (Hjeij et al., 2022). Depending on the application and pressure requirement, hydrogen can be stored in four different types of pressure vessels(Hjeij et al., 2022),:

- Type I Metal (steel/aluminium) vessels the cheapests and widely used for industrial gas storage
- Type II and III made of a metal liner partially or fully wrapped with a fibber-resin composite or carbon fibber, preferred for higher pressure applications
- Type IV made from a composite material such as carbon fibber and a plastic liner used in portable applications like fuel cell vehicles.
- Type V made of liner-less composite mainly used for space launch vehicles

Raw material costs will increasingly impact the industry, making SMEs more vulnerable to price volatility (VC, Interview 11, 2024). Thus, SMEs are more likely to focus on Type I compression vessels.

- **Liquefaction — Liquefied Hydrogen through Ships, Trains, and Lorries**

Liquefaction involves storing hydrogen at extremely low temperatures (-253°C), making it a technically challenging and energy intensive process with energy losses of ~ 40% (compared to ~ 20% for compressed hydrogen) (Zhang et al., 2023; VC, Interview 8, 2024; Arsad et al., 2023). (Zhang et al., 2023; Arsad et al., 2023). Due to these complexities, SME involvement is limited.

While the advantages of liquefaction include higher liquid density and enhanced storage efficiency, the process demands advanced cryogenic technologies, such as well-

insulated vessels with protective jackets and inner pressure vessels wrapped in aluminium film or coated with perlite to minimize thermal conductivity (Zhang et al., 2023; Arsad et al., 2023). These requirements make the sector highly specialised and challenging for SMEs to penetrate without targeted support.

However, SMEs can play a pivotal role in the liquefaction value chain by developing advanced materials for cryogenic conditions or improving sealing systems to prevent leakage (VC, Interview 8, 2024). SMEs are also relatively active in designing and manufacturing components for transportable cryogenic vessels, as well as safety and inspection systems under CEN/TC 268, although their participation in cutting-edge hydrogen infrastructure, such as refuelling systems for ships, trains, and road vehicles, remains limited (VC, Interview 11, 2024).

SMEs further support the sector through essential services like leak detection, vessel inspections, and maintenance, helping to address niche challenges and complement the efforts of larger companies (VC, Interview 8, 2024). With targeted investment and collaborative research opportunities, SMEs could strengthen their role in liquefaction technology, particularly in areas where tailored solutions are needed (Hydrogen Europe, 2021; VC, Interview 8, 2024).

- **Cooling Compression** — Cryo-compressed Hydrogen

In this compression method, hydrogen exists as a supercritical cryogenic gas, combining the properties of both compressed gaseous and cryogenic hydrogen systems (Moradi & Groth, 2019). Liquefaction is not required, and the gas is compressed to 300 bars at -233°C (Moradi & Groth, 2019). This method minimises the boil-off rate of hydrogen while maintaining high energy density (Moradi & Groth, 2019). Cryo-compression offers benefits such as high storage density, efficient refuelling, and enhanced safety due to vacuum enclosures (Moradi & Groth, 2019).

Significant challenges include the availability and cost of infrastructure, as well as the lower energy density by volume, which necessitates the use of large pressure vessels (Moradi & Groth, 2019). Based on this information, it appears that SMEs may be less prevalent in this sector, although further investigation is needed to confirm their involvement.

2) **Chemical Storage**

- **Chemical Sorption** — Metal Hybrid or Liquid Organic Hydrogen Carriers via Lorry

Metal hydrides, such as LiAlH4, are well-known materials used for chemical sorption (Dauletbay, 2024). These carriers can absorb and release hydrogen either at room temperature or when heated (Dauletbay, 2024). The main challenges associated with chemical sorption materials include cost, weight, and operating temperature, as well

as improving charge-discharge rates and controlling unwanted gas formation during desorption (Dauletbay, 2024). Given these challenges and the limited information available regarding SMEs in this area, it is likely that their presence is minimal.

- **Liquid Organic Hydrogen Carriers (LOHC)**

In this method, hydrogen is chemically bonded to hydrogen-lean molecules and released through catalytic dehydrogenation (Hren et al., 2023). LOHCs are attractive because they can be handled easily under ambient conditions, do not emit CO2 during storage and release, and can be reused repeatedly (Hren et al., 2023). Although these carriers are non-toxic and non-corrosive, their low storage capacity may limit their applications (Hren et al., 2023). As with liquid hydrogen transportation, it appears that SMEs may be less active in this sector (Chu et al., 2023).

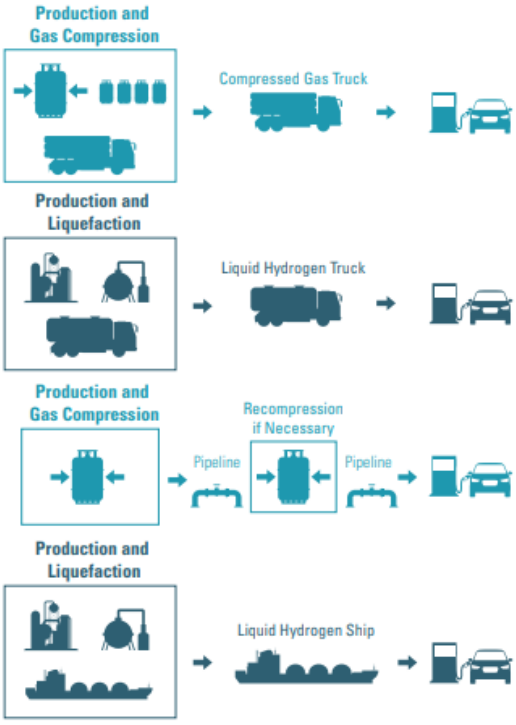
- **Physical Sorption** — Carbon Nanotubes or Metal Organic Frameworks via Lorries

Metal Organic Frameworks (MOFs) offer a promising alternative due to their high surface area, low hydrogen binding energy, faster charge-discharge kinetics, and lower material costs compared to carbon nanotubes (Sandhu et al., 2024). Carbon Nanotubes and MOFs provide enhanced safety for transportation because they operate at low storage pressure and possess predictable properties. However, they are not suitable for high-demand applications and are usually transported by road (Sandhu et al., 2024). The hydrogen storage industry utilising carbon nanotubes or MOFs is still largely in the research and development phase (Paul et al., 2023). Although there have been promising advancements, commercialisation is yet to achieve significant scale (Paul et al., 2023). Thus, it is less likely that SMEs will be involved in this field.

C) Distribution Technologies

Transporting hydrogen to its point of use poses challenges due to hydrogen's low density and flammability when mixed with even small amounts of air (Hydrogen Portal, 2022). This low volumetric energy density allows hydrogen to permeate metal-based materials making transportation costly, as the safeguards to avoid this phenomenon are difficult to put in place (Hydrogen Portal, 2022). As a result, it requires high pressures, low temperatures, or chemical processes to be stored compactly (Hydrogen Portal, 2022). Currently, hydrogen is primarily transported from production sites to usage locations via pipelines and road transport using liquid tanker trucks or gaseous tube trailers (Hydrogen Europe, 2021b). **Figure 15** illustrates the primary means of hydrogen transportation.

Figure 15 Primary Means of Hydrogen Transportation



Source: Hydrogen Portal, 2022

- **Pipelines**

SMEs face challenges entering the hydrogen pipeline sector due to the substantial investments required, which are often dominated by larger companies (Hydrogen Europe, 2021b). However, SMEs play crucial roles in distribution and maintenance, particularly at the local level (VC, Interview 8, 2024). For example, in Belgium, small firms handle local distribution, while in Germany, fragmented systems allow SMEs to manage specific pipelines (VC, Interview 8, 2024).

SMEs contribute through specialised services such as pipeline inspections, maintenance, safety solutions, and leak detection, which are essential given the complexities of hydrogen transport compared to natural gas (VC, Interview 8, 2024). They also support the adaptation of natural gas infrastructure for hydrogen, offering innovative technologies and local expertise for smaller-scale projects (VC, Interview 8, 2024).

- **Trucking — Compressed or Liquid Hydrogen Transported via Trucks**

Hydrogen transported via truck is typically hauled in either liquid tanker trailers or tube trailers (Hydrogen Portal, 2022). High-pressure cylinders and tube trailers operating

at ~2,600 pound-force per square inch (psi) are commonly used to distribute gaseous hydrogen within 200 miles of the source (Hydrogen Portal, 2022). Hydrogen transport by truck typically involves high-pressure tube trailers that operate at twice the pressure of normal transport (Hydrogen Portal, 2022). Liquid tanker trailers are used for transport distances of up to 600 miles (Hydrogen Portal, 2022). Cryogenic liquid hydrogen trailers operate at near atmospheric pressure (Hydrogen Portal, 2022). It has been difficult to determine whether SMEs are involved in this activity.

D) Utilisation Technologies

- **Fuel Cells (FCH)**

FCHs are devices that convert chemical energy from a fuel, typically hydrogen, into electricity through an electrochemical reaction with oxygen (Nebergall, 2022). The FCH sector includes a series of highly successful SMEs that have developed products and are eager to scale up to large-scale manufacturing to reduce costs and increase market penetration in response to growing demand (Clean Hydrogen Partnership, 2022).

- **Power-to-Gas (PtG)**

Power-to-Gas (PtG) converts surplus renewable energy into hydrogen for storage or injection into the natural gas grid. The commercialisation of power-to-gas technology is still in its early stages of development, with a limited number of pilot and demonstration plants either operational or under development (Lambert, 2018).

The production cost of renewable gas and all other green carbon-based fuels is predominantly driven by investment costs, operating costs of the PtG/PtX-plants and the operation hours per year (Sterner & Specht, 2021). Investment costs have fallen sharply over the past decade and continue to decline (Sterner & Specht, 2021). Operating costs are mainly related to renewable electricity, which is becoming increasingly affordable, as well as taxes, levies, and surcharges, which vary greatly and have been the biggest obstacle to the market introduction of PtG over the past decade (Sterner & Specht, 2021). As a result, SMEs could be present in this sector.

E) Conclusion

In conclusion, while large corporations dominate large-scale hydrogen production, SMEs play a crucial role in decentralised green production and innovations in storage, transportation, and infrastructure maintenance, offering flexible and scalable solutions that advance the hydrogen economy despite existing challenges.

EU Policies and legislation related to the Hydrogen Industry

The EU's strategy for hydrogen, launched in 2020, outlined a comprehensive policy framework to drive this transition. This strategy, known as the EU Strategy on Hydrogen (COM/2020/301), introduced policy initiatives in five key areas: investment support, fostering production and demand, creating a hydrogen market and infrastructure, promoting research and development, and enhancing international cooperation. Hydrogen also plays a central role in the broader EU Strategy for Energy System Integration (COM/2020/299), which highlights its contribution to a more flexible and sustainable energy system. By the first quarter of 2022, all 20 key hydrogen actions listed in the EU strategy had been implemented, underscoring the Commission's commitment to developing the hydrogen economy.

Building on this policy momentum, the European Commission published two Delegated Acts (DAs) under Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II) on 13 February 2023, directly addressing renewable hydrogen. One of these acts classifies hydrogen produced from renewable electricity as a "renewable fuel of non-biological origin", commonly referred to as green hydrogen. This regulation has significant implications for developers of wind and solar parks, as well as hydrogen plants, by setting conditions that affect the timing, location, and business cases of such projects. This is especially relevant for SMEs involved in renewable hydrogen production.

The second DA, establishes a methodology for calculating greenhouse gas savings from renewable fuels of non-biological origin. It supports the early scale-up of electrolysis by enabling producers to enter into long-term renewable power purchase agreements with existing installations until 1 January 2028. Together, these regulatory advancements align with previous calls by Hydrogen Europe for a robust framework to support the growth of the hydrogen sector (Hydrogen Europe, 2022).

Germany, the Netherlands, Poland, Italy, and France collectively account for 56% of Europe's hydrogen production capacity. This reflects the strong industrial bases of these countries in sectors such as refining and ammonia production (Clean Hydrogen JU, 2023). The hydrogen production capacity across Europe remains uneven, with the top eight countries representing 74% of total production capacity. The remaining 18 countries account for only 26% of the continent's total capacity (Clean Hydrogen JU, 2023).

Standardisation also plays a critical role in supporting hydrogen deployment across the EU. The Pressure Equipment Directive (PED) 2014/68/EU provides a framework for ensuring the safety of pressure equipment and assemblies operating at significant pressures, which are pivotal in hydrogen storage and transportation

systems.[29] Compliance with harmonised standards under the Directive offers a presumption of conformity, facilitating market access and legal certainty.[30]

The Industrial Emissions Directive (IED) aims to minimise the environmental impact of industrial activities, including facilities involved in hydrogen production, such as electrolysis and reforming plants.[31] Standards under the IED guide emission monitoring, safety protocols, and best practices for reducing environmental harm.[32]

The Alternative Fuels Infrastructure Regulation (AFIR) promotes the deployment of refuelling stations for hydrogen and other alternative fuels across the EU.[33] Standards, such as those developed by ISO/TC 197, are integral to the regulation, ensuring compatibility and safety in hydrogen refuelling systems.[34]

These policies and legislative measures emphasise the importance of standards in ensuring the safety, efficiency, and market compatibility of hydrogen technologies across the EU. Standardisation efforts are led by key technical committees, including CEN/TC 234, CENELEC/TC 268, and ISO/TC 197.

In conclusion, while the European Commission is clearly driving renewable hydrogen production through a strong regulatory and policy framework, it remains to be seen whether the industry will fully align with this ambition and scale up accordingly

Standardisation work on Hydrogen

This section outlines the TCs and WGs that are particularly relevant to SMEs within the hydrogen sector. The report focuses on TCs that are frequently highlighted in the DIN report on hydrogen and that are of interest for SMEs (DIN e.V., 2024).

[29] Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment (recast) [2014] OJ L189/164, recitals 14 and 28, art 12(1).
[30] Ibid., recital 28, art 12(1).
[31] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [2010] OJ L334/17, arts 1 and 2.
[32] Ibid, Art. 18; 70 (3)
[33] Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU [2023] OJ L231/1, arts 1 and 2.
[34] Ibid., Art. 21 (2) and Annex 2

Table 13 Technical Committees relevant to SMEs in the hydrogen industry

TCs	Scope	WGs
ISO/TC 197 Hydrogen Technologies	Systems and devices for the production, storage, transport, and use of hydrogen.	WG 27 - Hydrogen fuel quality WG 28 - Hydrogen quality control WG 29 - Safety of hydrogen systems
CEN/TC 234 Gas Infrastructure	Infrastructure for gas supply including pipelines and safety regulations.	WG 6 - Gas pressure regulation WG 11 - Gas Quality
CEN/CLC JTC 6 Hydrogen in Energy Systems	Systems for the production, storage, and distribution of hydrogen in energy systems.	WG 1 - Terms and Definitions; WG 2 - Guarantees of Origin
IEC/TC 105 Fuel Cell Technologies	Fuel cell systems used in stationary, portable, and transportation applications.	WG 22 - Fuelling station hoses. WG 24 - Fuelling protocols for hydrogen-fuelled vehicles
CEN/TC 58 Safety and Control Devices for Burners	Safety devices for equipment using gaseous or liquid fuels.	WG 15 - Hydrogen advisory group
ISO/TC 265 Carbon Capture and Storage	Technologies related to carbon dioxide capture and geological storage.	WG 1 – Capture (see annex)
CEN/TC 267 Industrial Piping and Pipelines	Metallic piping and systems, particularly for industrial applications.	WG 2 - Metallic materials WG 5 - Inspection and testing; WG 8 - Maintenance of EN 13480
ISO/TC 58 Gas Cylinders	Gas cylinders and pressure receptacles for various applications.	WG 7 - Gas compatibility WG 16 - Composite cylinders
CEN/TC 268 Cryogenic Vessels	Vessels used in storing and transporting liquefied gases, including hydrogen.	WG 5 - Specific hydrogen technologies applications
CLC/TC 8x System Aspects of Electrical Energy Supply	Standardisation to facilitate the functioning of electricity supply systems in open markets.	WG 02 - Domestic generation; WG 03 - Requirements for connection of generators to distribution networks; WG 05 - Smart grid requirements; WG 07 - Power frequency measurement for Distributed Energy Resources management

Challenges and obstacles

SMEs in the hydrogen industry face several challenges related to standardisation, which limit their ability to fully participate in the market (VC, Interview 6, 2024). One key issue is the uneven level of engagement in standardisation across EU Member States (VC, Interview 6, 2024; VC, Interview 11, 2024). While countries like Germany, France, and the Netherlands are active in these processes, others are significantly less involved (VC, Interview 6, 2024; VC, Interview 11, 2024). This disparity leaves SMEs from less active countries struggling to navigate the complexities of standardisation (VC, Interview 6, 2024).

Moreover, the standardisation process itself is inconsistent across countries and sectors (VC, Interview 6, 2024). In some cases, participation requires financial contributions, creating a barrier for smaller companies with limited budgets (VC, Interview 6, 2024). The lack of a harmonised approach adds to the difficulties that SMEs face in engaging with the process. Exacerbating this issue is the fact that many SMEs prioritise product development over building expertise in standardisation, often due to a lack of awareness about how strategically important it is for market access and competitiveness (VC, Interview 6, 2024).

Another significant challenge is the cost of international participation (VC, Interview 6, 2024). Attending global standardisation meetings can incur travel expenses that are substantial, sometimes amounting to tens of thousands of euros annually (VC, Interview 6, 2024). This financial burden is difficult to manage, even for larger companies, and can be particularly daunting for SMEs (VC, Interview 6, 2024). The reduction in travel budgets by major firms further complicates the situation, as it limits opportunities for SMEs to gain international exposure (VC, Interview 6, 2024).

Additionally, SMEs face significant challenges in attracting and retaining skilled engineers, a problem that is compounded by the lack of resources for training programs or competitive salaries (VC, Interview 11, 2024). Keeping track of updates in international treaties and standards (e.g., ADR regulations) places an additional administrative burden on smaller firms (VC, Interview 11, 2024).

To overcome these challenges, SMEs would benefit from greater support and guidance. For instance, a practical guide or digital tool could help businesses understand how to get involved in standardisation at the national, European, and international levels (VC, Interview 6, 2024). Additionally, the creation of a European fund to cover travel expenses for attending international meetings could relieve financial pressures and promote broader SME participation (VC, Interview 6, 2024). Ultimately, overcoming these hurdles would help SMEs better compete in the growing hydrogen industry.

Despite the existing production capacity, the hydrogen market lacks official and precise statistics, making it difficult to assess and challenging to monitor (Hydrogen Europe, 2022).

Conclusion

The hydrogen industry, while central to the EU's energy transition, poses significant challenges for SMEs. These include difficulties in accessing standardisation processes, uneven participation across Member States, and limited resources to engage in international standardisation activities.

To address these issues, SBS should take decisive action. Developing a practical guide for SMEs, in collaboration with Hydrogen Europe, would provide essential support by explaining the standardisation process, identifying funding opportunities, and offering clear instructions for involvement at various levels. Raising awareness about the strategic importance of standardisation through targeted campaigns and fostering partnerships with key organisations like Hydrogen Europe would also enhance the capacity of SMEs. By taking these steps, SBS can help SMEs overcome barriers and fully engage in this dynamic sector, ensuring a more inclusive and innovative hydrogen market.

2.8 BIOFUELS

Biofuel technologies

Biofuels are produced from organic materials, commonly referred to as biomass. The process involves converting these raw materials, which can be agricultural crops, waste, or other plant matter, into fuels that can be used for energy (Lee & Lavoie, 2013; Gragg, 2023). Biofuels can be split up into three categories: Solid biofuels (fuelwood, wood residues, wood pellets, ...), liquid biofuels (biodiesel, ethanol, ...), and biogases (from anaerobic fermentation and from thermal processes)

There are several methods for producing biofuels, depending on the type of fuel being produced and the feedstock used (Lee & Lavoie, 2013; European Court of Auditors, 2023; ETIP Bioenergy, 2020). Biofuels are usually classified as either first, second or third generation (Lee & Lavoie, 2013; European Court of Auditors, 2023; ETIP Bioenergy, 2020).

First-generation biofuels include ethanol and biodiesel and are directly related to biomass, often derived from edible feedtocks (Lee & Lavoie, 2013; European Court of Auditors, 2023; ETIP Bioenergy, 2020). Ethanol is generally produced from the fermentation of C_6 sugars (mainly glucose) (Lee & Lavoie, 2013). Other more marginal feedstocks that are used include but are not limited to whey, barley, potato waste, and sugar beets.

Second-generation biofuels are referred to as advanced biofuels as they require higher investments than first-generation biofuels (Lee & Lavoie, 2013; European Court of Auditors, 2023). They are fuels produced from a wide array of different feedstocks, primarily but not limited to non-edible lignocellulosic biomass. Biomass used for production of second-generation biofuels is usually separated into three main categories: homogeneous, such as white wood chips; quasi-homogeneous, such as agricultural and forest residues; and non-homogeneous, including low value feedstock as municipal solid waste.

Third-generation biofuels are fuels produced from algal biomass. The process focuses on extracting oils or fats from the algae, which are then turned into fuel. Algae types like *Chlorella* are often used because they contain a lot of oil (approximately 60-70%) and grow quickly, producing up to 7.4 grams per litre per day (Lee & Lavoie, 2013; Branco-Vieira et Al., 2020; Breuer & Popescu, 2023).

First-, second- and third-generation biofuels are converted from biomass to biofuel in a variety of ways: combustion, transesterification or hydrogenation, fermentation, anaerobic digestion and pyrolysis.

Combustion means burning organic material. In the process of combustion, two ingredients (biomass and oxygen) are combined in a high temperature environment to form carbon dioxide, water vapor, and heat (Biofuels Academy, 2024).

Transesterification is a process used to make biodiesel, where oils or fats from biomass are mixed with alcohol in the presence of a substance called a catalyst (Reddy et al., 2022). This catalyst helps speed up the reaction, allowing the fats or oils to convert into biodiesel more effectively (Reddy et al., 2022). Different types of catalysts can be used for this reaction, including acids, alkalis, and even enzymes (Reddy et al., 2022). Among the available alcohols, methanol is commonly used because it is both affordable and effective (Reddy et al., 2022).

The fermentation of biomass to produce biofuels is a multi-step process that begins with preparing the plant material, or feedstock, to make it easier to convert into fuel (Naveed et al., 2024). Once pretreated, the biomass undergoes hydrolysis, where long chains of sugars (polymers) in the biomass, like cellulose and hemicellulose, are broken down into simple sugar molecules (Naveed et al., 2024). The latter can be transformed into bioethanol through fermentation, the biological step where microorganisms like yeast or bacteria convert the sugars into alcohol (bioethanol) (Naveed et al., 2024).

Anaerobic Digestion (AD) is an established method for breaking down complex biowaste, such as food scraps and agricultural residues, to produce valuable products like hydrogen (H_2) and methane (CH_4) (Gong et al., 2021). AD converts waste into energy while also significantly reducing the biological and chemical oxygen demand of the material, decreasing its potential to pollute (Gong et al., 2021). However, the process requires strict oxygen-free conditions, as even a small amount of oxygen can disrupt certain stages, especially methanogenesis (Gong et al., 2021).

Pyrolysis is a process where organic materials, like wood or agricultural waste, are heated to high temperatures (typically between 250 and 600°C) without any oxygen present (Hoang et al., 2021). This heating causes the materials to break down into different products: solids (char), liquids (bio-oils), and gases which are then used as biofuels (Hoang et al., 2021). For a more graphic interpretation of the biofuels production process, you can observe **Table 14**.

Table 14 The conversion process of biofuels

Generation	Feedstock	Conversion routes	Converted into
1st	Oil Crops (Rape, Sunflower, etc), Waster Oil, Animal Fat	Combustion	Heat and/or Power
		Transesterification or Hydrogenation	Biodiesel/Renewable Diesel
	Sugar Starch Crops	Fermentation	Ethanol
		Anaerobic Digestion	Heat and/or Power Biomethane
2nd	Lignocellulosic Biomass (Wood, Straw, Energy Crop, MSW, etc)	Pyrolysis	Heat and/or Power
		Anaerobic Digestion	Heat and/or Power Biomethane
		Combustion	Heat and/or Power
	Biodegradable MSW (Farm and Food Waste)	Pyrolysis	Heat and/or Power
		Anaerobic Digestion	Heat and/or Power Biomethane
3rd	Algae	Transesterification	Biodiesel/Renewable Diesel

Source: https://www.youtube.com/watch?v=atmllcek2IA

Presence of SMEs in Biofuels

The diversity of biofuel producers is a key strength of the sector, encompassing a dynamic mix of small and large entities, as well as national and multinational players (VC, Interview 10, 2024). The European Biodiesel Board (EBB), for instance, represents this variety (VC, Interview 10, 2024). Most companies in the industry are not rooted in the fossil fuel business—a testament to a recent shift—but instead have strong ties to agricultural commodities or are specialised in waste-based biodiesel (VC, Interview 10, 2024).

Most SMEs involved in biofuels operate at the raw material production and extraction stage, rather than at the high-cost conversion stage (Hydrogen Europe, 2020; VC, Interview 10, 2024; European Union, 2022). As mentioned,, raw materials include products from agriculture and forestry as shown in table 19 under feedstock. The issue is that sometimes these raw materials are not sourced from Europe but from Brazil or the USA (Gragg, 2023). Therefore, this renewable energy source presents fewer opportunities for European SMEs and for SBS.

EU Policy and legislation related to Biofuels

The Commission adopted in June 2023 new rules establishing the share of biofuels and biogas in mixed fuels (European Commission, 2024f). Under the Renewable Energy Directive (RED), EU countries are obliged to ensure that the share of renewable energy in the final consumption of energy in transport is at least a minimum share of 3.5% advanced biofuels by 2030 (European Commission, 2024f).

Additionally, Article 26 of RED II defines sustainability requirements for biofuels and biomass, ensuring that their production does not lead to deforestation, damage biodiversity, or cause indirect land-use change (ILUC). Biomass must come from areas that were not converted from natural ecosystems after January 2008. Moreover, the article sets minimum greenhouse gas (GHG) emissions savings that biofuels must achieve compared to fossil fuels. For biofuels, the savings must be at least 50-65%, depending on the installation date. In addition, RED II limits the use of high-risk feedstocks for biofuel production, particularly those linked to ILUC. For example, palm oil has been classified as a high-risk feedstock under RED II, and its use is set to be phased out by 2030. In a 2016 study for the European Commission, it was found that biodiesel produced from palm oil and soybean oil emits more GHG than diesel oil (Statista, 2024). Overall, Article 26 of the Directive aims to promote the use of bioenergy in a way that supports climate goals without harming ecosystems or food security.

Part A of Annex IX to RED II lists advanced biofuels feedstocks that are eligible for special treatment under the directive. These feedstocks are considered to have a lower risk of ILUC and are typically derived from waste, residues, or non-food materials. Biofuels produced from these sources can count double towards national renewable energy targets in the transport sector.

From 15 January 2024, the Commission's Union Database for Biofuels (UDB), foreseen under Article 31a of the 2018 RED, is open for online registration by the relevant economic operators of transactions of liquid renewable and recycled carbon fuels. The UDB is a global traceability tool used to trace consignments of renewable and recycled carbon fuels, and the respective raw materials used for their production - from the point of origin of the raw materials to the point where fuels are put on the EU market for final consumption. It will help ensure market transparency and traceability in the supply chain for such fuels, mitigating the risk of irregularities and fraud, and thereby supporting efforts to meet the ambitious EU decarbonisation targets.

The RED also integrates articles that reference standards in the biofuels industry. Article 29 lays out sustainability and GHG emissions-saving criteria for biofuels, bioliquids, and biomass fuels. While the article does not name specific standards, it establishes the framework within which compliance with standards is essential for

ensuring that these fuels meet the required environmental and GHG reduction benchmarks. Article 30 highlights the necessity of robust methodologies and tools to verify adherence to the sustainability criteria outlined in Article 29.

The Fuel Quality Directive complements RED by targeting the carbon intensity of fuels used within the EU.[35] This directive mandates that biofuels meet sustainability criteria aligned with RED while adhering to specific quality standards, such as EN 14214 for biodiesel.[36]

The Industrial Emissions Directive establishes the Best Available Techniques (BAT) for controlling emissions in industrial plants, including facilities that use biofuels and biomass.[37] The BAT conclusions provide detailed technical requirements and standards for emissions and efficiency, fostering consistency across Member States.[38]

CEN and ISO have produced technical standards such as EN ISO 17225-1:2021 for solid biofuels, which defines fuel quality classes and specifications, and ISO 13065, which outlines sustainability criteria for bioenergy. These standards are crucial in ensuring technical and environmental compliance across the industry.

These legislative instruments and standards collectively provide a comprehensive framework for the biofuels and solid biomass sectors, promoting sustainability, reducing emissions, and ensuring the alignment of industrial practices with the EU's climate and energy objectives.

[35] Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel, and gasoil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC [2009] OJ L140/88, arts 7b and 7c.
[36] Ibid., Art. 7b (6); Annex II
[37] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [2010] OJ L334/17, art 2(1), art 11.
[38] Ibid., Art. 30; Annex 5, Part 1, 2 and 3).

Standardisation on Biofuels

This section presents the TCs and WGs that are relevant to SMEs in the Biofuels sector.

Table 15 Technical Committees on Biofuels

Direct TCs	Scope	WGs
CEN/TC 19 Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin	Methods of sampling, analysis and testing, terminology and specifications and classifications for petroleum related products, fuels, lubricants and hydraulic fluids, that origin from mineral oil and biomass.	JWG 1 Vegetable fats and oils and their by-products for use in automotive fuels
CEN/TC 335 Solid biofuels and Pyrogenic Biocarbon	Terminology, specifications and classes, sampling and sample preparation, test methods, and safety aspects in the field of raw and processed materials originating from arboriculture, agriculture, aquaculture, horticulture and forestry to be used as a source of thermally and non-thermally treated solid biofuels and pyrogenic biocarbon. (Same scope than ISO/TC 238 below)	No specific WGs (adoption of ISO standards- See ISO/TC 238 below)
CEN/TC 383 Sustainably produced biomass for energy applications	Sustainability principles, criteria and indicators, including greenhouse gas emissions savings, chain-of-custody aspects, their verification and auditing schemes, which primarily support EU Legislation.	WG 3 Biodiversity and environmental aspects
CEN/TC 408 Natural gas and biomethane for use in transport and biomethane for	Specification for renewable and low-carbon methane rich gases for injection in the gas network; natural gas, renewable and low-carbon methane rich gases and mixtures thereof as fuel for engine; production of	WG 1 Injection and fuel specification

injection in the natural gas grid	renewable and low-carbon methane rich gases.	
ISO/TC 238 Solid Biofuels and Pyrogenic Biocarbon ⇨	Terminology, specifications and classes, sampling and sample preparation, test methods, and safety aspects in the field of raw and processed materials originating from arboriculture, agriculture, aquaculture, horticulture and forestry to be used as a source of thermally and non-thermally treated solid biofuels and pyrogenic biocarbon.	WG 1 Terminology; WG 2 Fuel specifications and classes WG 4 Physical and mechanical test methods WG 5 Chemical test methods WG 6 Sampling and sample preparation WG 7 Safety of solid biofuels
ISO/TC 255 Biogas	Biogas produced by anaerobic digestion, gasification from biomass and power to gas from biomass sources.	WG 1 Terms, definitions and classification WG 4 Safety and environmental aspects WG 6 Biomass gasification
CEN/TC 454 Algae and algae products	Specification, classification, terminology methods and energy applications for algae and algae-based products immediately derived from or used in algae production processes.	WG 5 Specifications for non-food/feed sector applications

Challenges and obstacles

The production of biofuels faces certain challenges. It is particularly hindered by the absence of reliable supply chain frameworks and high feedstock costs (Zahraee et al., 2020; Narwane et al., 2021). Effective planning tools for overcoming biomass supply chain challenges are crucial for both academic research and industrial applications (Zahraee et al., 2020). Perhaps, the recently implemented UDB will enhance the traceability of biomass feedstock and allow for more transparency within the industry, thereby increasing the predictability of production.

Given that these issues largely pertain to the extraction of raw materials, they are of particularly relevant to SMEs.

Conclusion

The analysis reveals that while biofuels present significant opportunities for decarbonisation, the sector is heavily dominated by large corporations, leaving SMEs primarily confined to raw material production. To support SMEs' participation in standardisation, SBS should prioritise engaging with TCs such as CEN/TC 335 Solid Biofuels, as it directly aligns with SME activities in raw materials and preliminary processes. SBS should also focus on enhancing SME access to EU initiatives like the Union Database for Biofuels (UDB) and promoting awareness of relevant standards to ensure SME compliance and competitiveness in the biofuels industry.

3. CONCLUSION

The renewable energy sector presents both opportunities and challenges for SMEs. To ensure that they remain competitive, sustainable, and integrated into Europe's renewable energy transition, SBS should implement the following strategic actions:

1. Strengthen SME Participation in Standardisation

- Identifying experts in areas related to the following Working Groups (WGs): ISO/TC 160 WG 9 and CEN/CLC JTC 10 WG 5 for Solar PV; ISO/TC 180 WG 4 and CEN/TC 312 WG 1 for Solar Thermal Energy; ISO/TC 339 for Hydropower; CEN/TC 10 WG 11 for Wind; CEN/TC 151/WG 3 for Geothermal; EC TC 114 for Ocean; ISO/TC 238 WG 7 and CEN/TC 335 for Biofuels.
- Collaborate with the following associations: SolarPower Europe for solar PV, SolarHeat Europe for solar thermal, European Renewable Energy Federation for hydropower and for other small-scale operators of renewable energy power plants, HydrogenEurope for hydrogen, European Geothermal Energy Confederation for geothermal energy, European Biodiesel Board for biofuels, Wind Europe for wind and Ocean Energy Europe for the ocean energy.

2. Raise Awareness and Build Capacity

- Develop practical guides in collaboration with sectoral stakeholders like Hydrogen Europe on how to engage in standardisation
- Expand future research to include areas not addressed or only superficially explored topics such as batteries, energy storage, grid connections, and energy management, potentially in collaboration with other organisations.
- Promote certifications such as the CEN Solar Keymark for solar thermal.
- Organise (an) event(s) on standardisation for SMEs in the renewable energy sector.

3. Advocate for SME-Friendly Policies and Funding

- Support streamlined permitting processes for hydropower and geothermal projects.
- Develop tailored financial mechanisms, such as travel grants for international standardisation meetings, in collaboration with other organisations like HydrogenEurope which was favourable of this idea.

By implementing these recommendations, SBS can empower SMEs to overcome barriers, drive innovation, and contribute to a sustainable and inclusive renewable energy landscape in Europe.

BIBLIOGRAPHY

European Union Legislation

Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC [1998] OJ L350/58.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [2009] OJ L140/16.

Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel, and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC [2009] OJ L140/88.

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products [2009] OJ L285/10

Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [2010] OJ L334/17.

Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment (recast) [2014] OJ L189/164.

Directive 2018/2001/EU of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) [2018] OJ L328/82.

Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 [2023] OJ L282/65.

Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU [2017] OJ L198/1.

Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU [2017] OJ L198/1

Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU [2023] OJ L231/1.

Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of Ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC [2024] OJ L216/1.

Directive (EU) 2024/1275 of the European Parliament and of the Council of 15 May 2024 on the energy performance of buildings (recast) [2024] OJ L158/102.

Secondary Literature

Alternative Energy Tutorials. (2024). *Tidal Stream and Tidal Stream Energy Devices of the Sea*. https://www.alternative-energy-tutorials.com/tidal-energy/tidal-stream.html

Alonso Viña, D. (2024, October). Los startups europeos de energía renovable luchan contra su principal obstáculo: la financiación. *Cinco Días*.

BBC. (2024, July 17). *How does geothermal energy work?* BBC Bitesize. https://www.bbc.co.uk/bitesize/articles/z4dhxbk#zy9cwsg

Biofuels Academy. (2024). *Combustion*. Biofuels Academy Combustion Comments. http://www.biofuelsacademy.org/index.html%3Fp=676.html

Branco-Vieira, M., Mata, T. M., Martins, A. A., Freitas, M. A. V., & Caetano, N. S. (2020). Economic Analysis of microalgae biodiesel production in a small-scale facility. Energy Reports, 6, 325–332. https://doi.org/10.1016/j.egyr.2020.11.156

Breuer, M., & Popescu, I. (2023). The future of the EU Algae Sector | European Parliament. www.europarl.europa.eu. https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733114/IPOL_STU(2023)733114_EN.pdf

Brownlie, F., Hodgkiess, T., Pearson, A., & Galloway, A. M. (2021). A study on the erosion-corrosion behaviour of engineering materials used in the geothermal industry. *Wear*, *477*, 203821. https://doi.org/10.1016/j.wear.2021.203821

Casey, J. (2021, December 28). *The unique challenges of hydropower dams around the world*. Power Technology. https://www.power-technology.com/features/hydropower-challenges-dams-world-projects/

Catapult Offshore Renewable Energies. (2024). Tidal Stream Technology Roadmap. ore.catapult.org.uk. https://cms.ore.catapult.org.uk/wp-content/uploads/2024/03/ORECatapult-Tidal-stream-roadmap-report.pdf

CEN. (2013). *CEN/TC 54 Business Plan*. standards.cencenelec.eu. https://standards.cencenelec.eu/BPCEN/6038.pdf

CEN. (2019). *CEN Guide 17 -- Safety of pressure equipment - Rules and recommendations for the drafting and presentation of safety standards*. cen.eu. https://boss.cen.eu/media/CEN/ref/cen_17.pdf

CENELEC. (2022). *Business plan CENELEC/TC or SC 88*. standards.cencenelec.eu. https://standards.cencenelec.eu/BPCLC/BP_TC_88.pdf

Christensen, L., Friis-Madsen, E., & Kofoed, J. P. (2005). The Wave Energy Challenge: the Wave Dragon case. In Proceedings of the POWER-GEN 2005 Europe Conference: Milan, Italy, June 2005

Chu, C., Wu, K., Luo, B., Cao, Q., & Zhang, H. (2023). Hydrogen storage by liquid organic hydrogen carriers: Catalyst, renewable carrier, and Technology – A Review. Carbon Resources Conversion, 6(4), 334–351. https://doi.org/10.1016/j.crcon.2023.03.007

Clean Hydrogen JU. (2023, November). *The European Hydrogen Market Landscape*. observatory.clean-hydrogen.europa.eu. https://observatory.clean-hydrogen.europa.eu/sites/default/files/2023-11/Report%2001%20-%20November%202023%20-%20The%20European%20hydrogen%20market%20landscape.pdf

Clean Hydrogen Partnership. (2022). Strategic Research and Innovation Agenda 2021 – 2027 . www.clean-hydrogen.europa.eu. https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20%28ID%2013246486%29.pdf

Corà, E. (2020). *Hydropower-europe*. ydropower-europe.eu. https://hydropower-europe.eu/uploads/news/media/The state of the art of hydropower industry-1600164483.pdf

Cortés, A., Feijoo, G., Chica, A., Da Costa-Serra, J. F., & Moreira, M. T. (2019). Environmental implications of biohydrogen based energy production from steam reforming of alcoholic waste. Industrial Crops and Products, 138, 111465. https://doi.org/10.1016/j.indcrop.2019.111465

Costanzo, G., & Brindley, G. (2023). Wind energy in Europe: 2023 statistics and the outlook for 2024-2030. Wind Europe. https://proceedings.windeurope.org/biplatform/rails/active_storage/disk/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaDdDVG9JYTJWNVNTSWhPV050WW1GMmFXaG5Zbk0xZFRsaGNHWTJlakY1T1RaaFpEUTNNQVk2QmtWVU9oQmthWE53YjNOcGRHbHZia2tpQVk1cGJteHBibVU3SUdacGJHVnVZVzFsUFNKWGFXNWtSWFZ5YjNCbElDMGdWMmx1WkNCbGJtVnlaM2tnYVc0Z1JYVnliM0JsSUMwZ01qQXlNeTV3WkdZaU95Qm1hV3hsYm1GdFpTbzlWVlJHTFRnbkoxZHBibVJGZFhKdmNHVWxNakF0SlRJd1YybHVaQ1V5TUdWdVpYSm5lU1V5TUdsdUpUSXdSWFZ5YjNCbEpUSXdMU1V5TURJd01qTXVjR1JtQmpzR1ZEb1JZMjl1ZEdWdWRGOTBlWEJsU1NJVVlYQndiR2xqWVhScGIyNHZjR1JtQmpzR1ZEb1JjMlZ5ZG1salpWOXVZVzFsT2dwc2IyTmhiQT09IiwiZXhwIjoiMjAyNC0wOS0xN1QxMTo0MjowMi4wMzRaIiwicHVyIjoiYmxvYl9rZXkifX0=--a31b399399e4550be86f58db22e688f0bd842656/WindEurope%20-%20Wind%20energy%20in%20Europe%20-%202023.pdf

Cuadra, L., Salcedo-Sanz, S., Nieto-Borge, J. C., Alexandre, E., & Rodríguez, G. (2016). Computational intelligence in wave energy: Comprehensive Review and Case Study. *Renewable and Sustainable Energy Reviews*, *58*, 1223–1246. https://doi.org/10.1016/j.rser.2015.12.253

Dauletbay, A. (2024). Transportation of hydrogen: Hydrogen usage. *Hydrogen Technologies - Advances, Insights, and Applications*. https://doi.org/10.5772/intechopen.1005066

De Dricus, R. (2023, March 29). *Solar concentrators: What are the different technologies?*. Manage risks and maximize ROI for your PV and energy storage projects.

https://sinovoltaics.com/learning-center/technologies/solar-concentrators-different-technologies/

Draghi, M. (2024, September). *The future of European competitiveness*. commission.europa.eu. https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The+future+of+European+competitiveness+_+A+competitiveness+strategy+for+Europe.pdf

Dulian, M. (2023, October). *Geothermal energy in the EU - european parliament*. www.europarl.europa.eu. https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/754566/EPRS_BRI(2023)754566_EN.pdf

Dumas, P. (2024). *Prospects of geothermal energy in Europe*. www.geothermica.eu. http://www.geothermica.eu/media/about-geothermal/Presentation-Slovenia-Prospects-of-Geothermal-Energy-in-Europe-PD.pdf

EBP US, Inc. (2022). Economic contribution of the European lead battery industry. www.eurobat.org. https://www.eurobat.org/wp-content/uploads/2022/04/Economic_Impact_of_European_Lead_Batteries_FINAL_02_24_22.pdf

EconMarketResearch. (2023, October). *Solar concentrator market size, share, revenue by 2031*. Econ Market Research. https://www.econmarketresearch.com/industry-report/solar-concentrator-market/

EGEC Geothermal. (2024, February 9). *Set plan geothermal implementation working groups - EGEC - european geothermal energy council*. https://www.egec.org/set-plan-h2020/

Enel. (2024). *Wind Turbine*. what it is, parts and working | Enel Green Power. https://www.enelgreenpower.com/learning-hub/renewable-energies/wind-energy/wind-turbineFlower Turbines. (2024). *Patents*. https://www.flowerturbines.com/patents LM Wind Power. (2024). *Blade recycling: LM wind power*. renewable power. https://www.lmwindpower.com/en/sustainability/blade-recycling

ETIP Bioenergy. (2020). *Status of advanced biofuels demonstrations in Europe*. www.etipbioenergy.eu. https://www.etipbioenergy.eu/current-status-of-advanced-biofuels-demonstrations-in-europe

Euractiv. (2018, June 8). *EURACTIV Press Release Site*. EURACTIV PR. https://pr.euractiv.com/pr/joint-centc-312-thermal-solar-systems-and-components-and-solar-heat-europeestif-workshop-next

ERIKSSON, S., BERNHOFF, H., & LEIJON, M. (2008). Evaluation of different turbine concepts for wind power. *Renewable and Sustainable Energy Reviews*, *12*(5), 1419–1434. https://doi.org/10.1016/j.rser.2006.05.017

EurObserv'ER. (2023, July 4). *Solar thermal and concentrated solar power barometer 2023*. https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2023/

European Commission. (2020). Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. eur-lex.europa.eu. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0741

European Commission. (2023, October 24). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS European Wind Power Action Plan* . eur-lex.europa.eu. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0669

European Commission. (2024a). *Solar energy*. energy.ec.europa.eu. https://energy.ec.europa.eu/topics/renewable-energy/solar-energy_en#:~:text=EU%20solar%20energy%20strategy,-As%20part%20of&text=It%20aims%20to%20deliver%20over,EU%2F2023%2F2413).

European Commission. (2024b). *European wind charter*. energy.ec.europa.eu. https://energy.ec.europa.eu/system/files/2023-12/Charter_logos_final_02.pdf

European Commission. (2024c). *Ocean Energy*. Research and innovation. https://research-and-innovation.ec.europa.eu/research-area/energy/ocean-energy_en#:~:text=What%20the%20EU%20is%20doing,for%20project%20developers%20and%20investors

European Commission. (2024d). Commission approves up to €6.9 billion of State aid by seven Member States for the third Important Project of Common European Interest in the hydrogen value chain. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/IP_24_789

European Commission. (2024f). *Biofuels*. Energy. https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biofuels_en#:~:text=Biofuels%20and%20biogas%20in%20co%2Dprocessed%20fuels,-The%20Commission%20adopted&text=Under%20the%20Renewable%20Energy%20Directive,of%203.5%25%20of%20advanced%20biofuels

European Court of Auditors. (2023). The EU's support for Sustainable Biofuels in Transport. www.eca.europa.eu. https://www.eca.europa.eu/ECAPublications/SR-2023-29/SR-2023-29_EN.pdf

European Environment Agency. (2023, February 28). *The natura 2000 Protected Areas Network*. https://www.eea.europa.eu/themes/biodiversity/natura-2000/the-natura-2000-protected-areas-network

European Industrial Gases Association AISBL. (2014). *Hydrogen Pipeline Systems*. www.eiga.eu. https://www.eiga.eu/uploads/documents/DOC121.pdf

European Renewable Energies Federation. (2023, October 5). Small hydropower in Europe. eref-europe.org. https://eref-europe.org/small-hydropower-in-europe/

European Solar Manufacturing Council. (2023). How to address the unsustainably low PV module prices to ensure a renaissance of the PV industry in Europe . esmc.solar. https://esmc.solar/wp-content/uploads/2023/09/SUPPORTING-DOCUMENT-How-to-adress-the-unsustainably-low-PV-module-prices-to-ensure-a-renaissance-of-the-PV-industry-in-Europe.pdf

European Union. (2022). Advanced biofuels in the European Union. www.etipbioenergy.eu. https://www.etipbioenergy.eu/images/Advanced Biofuels - CETO Report 2022.pdf

Foteinis, S. (2022). Wave Energy Converters in low energy seas: Current state and opportunities. *Renewable and Sustainable Energy Reviews*, *162*, 112448. https://doi.org/10.1016/j.rser.2022.112448

Franz, J., Morse, S., & Pearce, J. M. (2022). Low-cost pole and wire photovoltaic racking. *Energy for Sustainable Development, 68*, 501–511. https://doi.org/10.1016/j.esd.2022.05.007

Fuergy. (2019). *Hydroelectricity: Major challenges and issues*. https://www.fuergy.com/blog/hydroelectricity-major-challenges-and-issues

Fyns Kran Udstyr A/S. (2024). *We do lifting*. FYNS KRAN UDSTYR A/S. https://wedolifting.com/

Gailly, J. (2024). *5 challenges to ensure wind energy development through the Energy Transition*. Alcimed. https://www.alcimed.com/en/insights/wind-energy-development/

Gallman, P. (2011). *Green Alternatives and National Energy Strategy*. https://doi.org/10.1353/book.1870

Garabetian, T. (2019). *Report on competitiveness of the geothermal industry*. etip-geothermal.eu. https://etip-geothermal.eu/front/wp-content/uploads/D4.6-Report-on-Competitiveness.pdf

Geo-Energy Europe. (2019). *About*. www.geoenergyeurope.com. https://www.geoenergyeurope.com/about

Geo-Energy Europe. (2019b). *Members*. List of GEO-ENERGY EUROPE metacluster members. https://www.geoenergyeurope.com/members

Geo-Energy Europe. (2024). Welcome to geo-energy Europe. Welcome to GEO-ENERGY EUROPE. https://www.geoenergyeurope.com/

Gong, C., Singh, A., Singh, P., & Singh, A. (2021). Anaerobic Digestion of Agri-Food Wastes for Generating Biofuels. *Indian journal of microbiology*, *61*(4), 427–440. https://doi.org/10.1007/s12088-021-00977-9

Gragg, D. (2023, May 22). *Biofuels Lecture*. YouTube. https://www.youtube.com/watch?v=atmIlcek2IA

Green Economy. (2024). *Falling short: Challenges and solutions for the UK's struggling wind energy sector*. https://www.greenintelligence.org.uk/news/falling-short-challenges-and-solutions-for-the-uk-s-struggling-wind-energy-sector/

Green Rhino Energy Ltd. (2016). Value chain activity: Manufacturing wafers. Ingots & Wafers | Solar Value Chain. https://www.greenrhinoenergy.com/solar/industry/ind_02_wafers.php

Guo, B., Wang, T., Jin, S., Duan, S., Yang, K., & Zhao, Y. (2022). A review of Point Absorber Wave Energy Converters. Journal of Marine Science and Engineering, 10(10), 1534. https://doi.org/10.3390/jmse10101534

Hasan, M., & Manasseh, R. (2014). *Dissipation in Oscillating Water Columns*.

Hernandez-Estrada, E., Lastres-Danguillecourt, O., Robles-Ocampo, J. B., Lopez-Lopez, A., Sevilla-Camacho, P. Y., Perez-Sariñana, B. Y., & Dorrego-Portela, J. R. (2021). Considerations for the structural analysis and design of Wind Turbine Towers: A Review. *Renewable and Sustainable Energy Reviews*, *137*, 110447. https://doi.org/10.1016/j.rser.2020.110447

Hjeij, D., Biçer, Y., & Koç, M. (2022). Hydrogen strategy as an energy transition and Economic Transformation Avenue for natural gas exporting countries: Qatar as a case study. *International Journal of Hydrogen Energy*, *47*(8), 4977–5009. https://doi.org/10.1016/j.ijhydene.2021.11.151

Hoang, A. T., Ong, H. C., Fattah, I. M., Chong, C. T., Cheng, C. K., Sakthivel, R., & Ok, Y. S. (2021). Progress on the lignocellulosic biomass pyrolysis for biofuel production toward Environmental Sustainability. *Fuel Processing Technology*, *223*, 106997. https://doi.org/10.1016/j.fuproc.2021.106997

Hren, R., Vujanović, A., Van Fan, Y., Klemeš, J. J., Krajnc, D., & Čuček, L. (2023). Hydrogen production, storage and Transport for Renewable Energy and Chemicals: An environmental footprint assessment. Renewable and Sustainable Energy Reviews, 173, 113113. https://doi.org/10.1016/j.rser.2022.113113

Hydrogen Europe. (2020). Strategic Research and Innovation Agenda Final Draft ... hydrogeneurope.eu. https://hydrogeneurope.eu/wp-content/uploads/2021/11/20201027-SRIA-CHE-final-draft.pdf

Hydrogen Europe. (2021). *Strategic Research and Innovation Agenda Final Draf*. hydrogeneurope.eu. https://hydrogeneurope.eu/wp-content/uploads/2021/11/20201027-SRIA-CHE-final-draft.pdf

Hydrogen Europe. (2021b). *Tech - overview_hydrogen Transport & Distribution*. hydrogeneurope.eu. https://hydrogeneurope.eu/wp-content/uploads/2021/11/Tech-Overview_Hydrogen-Transport-Distribution.pdf

Hydrogen Europe. (2022). *A regulatory framework fit for a European hydrogen market*. hydrogeneurope.eu. https://hydrogeneurope.eu/wp-content/uploads/2022/06/220609-A-regulatory-framework-fit-for-a-European-h2-market-Final-2.pdf

Hydrogen Portal. (2022, July 26). *Transportation and Storage*. https://hydrogen-portal.com/technologies/transportation-and-storage/

Idrissov, C. (2024, April 12). Electrolyzer market: Consistent uptick in number of green H2 players. IDTechEx. https://www.idtechex.com/en/research-article/electrolyzer-market-consistent-uptick-in-number-of-green-h2-players/30861

IEA. (2021). Austria - Countries & Regions. www.iea.org. https://www.iea.org/countries/austria/energy-mix

IEA. (2021b). Norway - Countries & Regions. https://www.iea.org/countries/norway/energy-mix
IEA. (2022). The potential of digital business models in the New Energy Economy – analysis. https://www.iea.org/articles/the-potential-of-digital-business-models-in-the-new-energy-economy
IEA. (2022b). Lithuania Electricity Security Policy – analysis. https://www.iea.org/articles/lithuania-electricity-security-policy
Irena. (2015). *Solar heat for industrial processes technology brief*. www.irena.org. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf
IRENA. (2022). *Ocean Energy*. https://www.irena.org/Energy-Transition/Technology/Ocean-energy#:~:text=Wave%20energy%2C%20whereby%20converters%20capture,make%20use%20of%20height%20differences.
Ismaila, A., Chen, X., Gao, X., & Fan, X. (2020). Thermodynamic analysis of steam reforming of glycerol for hydrogen production at atmospheric pressure. Frontiers of Chemical Science and Engineering, 15(1), 60–71. https://doi.org/10.1007/s11705-020-1975-0
Karki, S., Haapala, K. R., & Fronk, B. M. (2019, August 7). *Technical and economic feasibility of solar flat-plate collector thermal energy systems for small and medium manufacturers*. Applied Energy. https://www.osti.gov/servlets/purl/1865813#:~:text=An%20industrial%20solar%20thermal%20energy,or%20a%20glycol%2Fwater%20mixture.
Kaur, P., & Verma, G. (2024). A critical assessment of aluminum-water reaction for on-site hydrogen-powered applications. Materials Today Energy, 101508. https://doi.org/10.1016/j.mtener.2024.101508
Kempener, R., & Neumann, F. (2014). *Tidal Energy Technology Brief*. www.irena.org. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/Tidal_Energy_V4_WEB.pdf
Kleinwasserkraft Österreich. (2024). *Kraftwerkstypen*. Kleinwasserkraft sterreich. https://kleinwasserkraft.at/kleinwasserkraft/technik/kraftwerkstypen/
Kleinwasserkraft Österreich. (2024b). Die Turbinentypen. Kleinwasserkraft sterreich. https://kleinwasserkraft.at/kleinwasserkraft/technik/turbinen/

KRASNODĘBSKI, Z. (2023, December 12). *Report on geothermal energy: A9-0432/2023: European Parliament*. REPORT on geothermal energy | A9-0432/2023 | European Parliament. https://www.europarl.europa.eu/doceo/document/A-9-2023-0432_EN.html#_section1
Lambert, M. (2018). Power-to-Gas: Linking Electricity and Gas in a Decarbonising World? . www.oxfordenergy.org. https://www.oxfordenergy.org/wpcms/wp-

content/uploads/2018/10/Power-to-Gas-Linking-Electricity-and-Gas-in-a-Decarbonising-World-Insight-39.pdf

Lee, R. A., & Lavoie, J.-M. (2013). From first- to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity. *Animal Frontiers*, *3*(2), 6–11. https://doi.org/10.2527/af.2013-0010

Market Research. (2024, August 1). *Wind turbine rotor blade market size, growth: Cagr of 9.2%*. MarketResearch.biz. https://marketresearch.biz/report/wind-turbine-rotor-blade-market/

Massenza. (2024, August 22). *Drilling rigs for sale - massenza drilling rigs*. www.massenzarigs.com. https://www.massenzarigs.com/

Moradi, R., & Groth, K. M. (2019). Hydrogen storage and delivery: Review of the State of the art technologies and risk and reliability analysis. *International Journal of Hydrogen Energy*, *44*(23), 12254–12269. https://doi.org/10.1016/j.ijhydene.2019.03.041

Mordor Intelligence Private Limited. (2024). Wind turbine rotor blade market share, Size & Manufacturers. Wind Turbine Rotor Blade Market Share, Size & Manufacturers. https://www.mordorintelligence.com/industry-reports/wind-turbine-rotor-blades-market

Narwane, V. S., Yadav, V. S., Raut, R. D., Narkhede, B. E., & Gardas, B. B. (2021). Sustainable development challenges of the biofuel industry in India based on integrated MCDM approach. *Renewable Energy*, *164*, 298–309. https://doi.org/10.1016/j.renene.2020.09.077

Naveed, M. H., Khan, M. N., Mukarram, M., Naqvi, S. R., Abdullah, A., Haq, Z. U., Ullah, H., & Mohamadi, H. A. (2024). Cellulosic biomass fermentation for biofuel production: Review of Artificial Intelligence Approaches. *Renewable and Sustainable Energy Reviews*, *189*, 113906. https://doi.org/10.1016/j.rser.2023.113906

Nebergall, J. (2022). Hydrogen internal combustion engines and hydrogen fuel cells | Cummins Inc.. www.cummins.com. https://www.cummins.com/news/2022/01/27/hydrogen-internal-combustion-engines-and-hydrogen-fuel-cells

NorHydro. (2024). Small hydropower plants. www.norhydro.com. https://www.norhydro.com/t-en

Ocean Energy Europe. (2022, March 2). *Financing Ocean Energy Farms*. https://www.oceanenergy-europe.eu/policy-topics/finance/

Ocean Energy Europe. (2023). Ocean Energy Key trends and statistics 2022. www.oceanenergy-europe.eu. https://www.oceanenergy-europe.eu/wp-content/uploads/2023/03/Ocean-Energy-Key-Trends-and-Statistics-2022.pdf

Ocean Energy Europe. (2023b, December 6). *EU Energy & Climate policy*. https://www.oceanenergy-europe.eu/policy-topics/climate-energy/

Ocean Energy Europe. (2024, July 24). *Wave energy*. https://www.oceanenergy-europe.eu/ocean-energy/wave-energy/

Ocean Energy Service. (2024). *Overtopping devices*. OES|IEA. https://www.ocean-energy-systems.org/what-is-ocean-energy/waves/overtopping-devices/

Office of Energy Efficiency & Renewable Energy (USA). (2024). Solar Photovoltaic Manufacturing Basics | Department of Energy. https://www.energy.gov/eere/solar/solar-photovoltaic-manufacturing-basics

Ormazabal Velatia. (2023, October 30). *Tidal Energy, what is and how does it work?*. Ormazabal. https://www.ormazabal.com/en-gb/tidal-energy-what-is-and-how-does-it-work/

Paul, T., Juma, A., Alqerem, R., Karanikolos, G., Arafat, H. A., & Dumée, L. F. (2023). Scale-up of metal-organic frameworks production: Engineering strategies and prospects towards sustainable manufacturing. *Journal of Environmental Chemical Engineering*, *11*(5), 111112. https://doi.org/10.1016/j.jece.2023.111112

Reddy, C. N., Vineetha, Y., Priyanka, A., Shalini, A., Mishra, B., Rajasri, Y., & Swapna, V. (2022). Techno-economic and Environmental Impact Analysis of biofuels produced from microalgal biomass. *Biofuels and Bioenergy*, 687–712. https://doi.org/10.1016/b978-0-323-90040-9.00006-0

Rees, M. (2017, July 23). Against the economic cycle: Small businesses and offshore wind. European Investment Bank. https://www.eib.org/en/stories/against-the-economic-cycle-small-businesses-and-offshore-wind

Reinsch, W. A., Broadbent, M., Denamiel, T., & Shammas, E. (2024). Friendshoring the lithium-ion battery supply chain: Final Assembly and end uses. CSIS. https://www.csis.org/analysis/friendshoring-lithium-ion-battery-supply-chain-final-assembly-and-end-uses

Renewable UK. (2014). Small and medium wind strategy. cdn.ymaws.com. https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/Docs/small_medium_wind_strategy_r.pdf

Roots Analysis. (2024, August 27). Inverter Market Size & Share Report, 2035. www.rootsanalysis.com. https://www.rootsanalysis.com/inverter-market

Sandhu, Z. A., Raza, M. A., Awwad, N. S., Ibrahium, H. A., Farwa, U., Ashraf, S., Dildar, A., Fatima, E., Ashraf, S., & Ali, F. (2024). Metal–organic frameworks for next-generation Energy Storage Devices; a systematic review. *Materials Advances*, *5*(1), 30–50. https://doi.org/10.1039/d3ma00822c

Sang, Y., Karayaka, H. B., Yan, Y., Yilmaz, N., & Souders, D. (2018). 1.18 ocean (marine) energy. *Comprehensive Energy Systems*, 733–769. https://doi.org/10.1016/b978-0-12-809597-3.00120-6

Schmid, M., Gonzalez Ramon, N., Dierckx, A., & Wegman, T. (2020). *Accelerating wind turbine blade circularity*. windeurope.org. https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Accelerating-wind-turbine-blade-circularity.pdf

Scott, A. (2023, July 26). Flow batteries, the Forgotten Energy Storage Device. Chemical & Engineering News. https://cen.acs.org/materials/energy-storage/Flow-batteries-forgotten-energy-storage/101/i25

Seo, S., Kim, J., Muljadi, E., Nelms, R. M., & Moeljanto, H. (2022). Holistic design of small-scale oscillating water column in stand-alone DC Microgrid. *2022 IEEE Energy Conversion Congress and Exposition (ECCE)*. https://doi.org/10.1109/ecce50734.2022.9947376

Sino Voltaics. (2024). Europe Solar Supply Chain. media-01.imu.nl. https://media-01.imu.nl/storage/sinovoltaics.com/14240/sinovoltaics-solar-supply-chain-map_europe_q1-2024.pdf

Småkraft AS. (2024, June 3). About småkraft. en.smaakraft.no. https://en.smaakraft.no/about-smakraft-as/

Solar Heat Europe. (2022). A solar thermal roadmap for Europe. solariseheat.eu. https://solariseheat.eu/wp-content/uploads/2022/12/Energising-Europe-Solar-Heat-STroadmap2030.pdf

Solar Heat Europe. (2023). Solar thermal market outlook 2022/2023. solariseheat.eu. https://solarheateurope.eu/wp-content/uploads/2023/10/INFOGRAPHY_SOLARHEATEUROPE_OCT23_FINAL.pdf

Solar Heat Europe. (2024). SOLAR HEAT IS SMART Manifesto for the Incoming European Legislators. solarheateurope.eu. https://solarheateurope.eu/wp-content/uploads/2024/04/SHE-Manifesto2024-final.pdf

SolarPower Europe. (2024). Global market outlook for solar power 2024 - 2028. solar. Global_Market_Outlook_for_Solar_Power_2024_a083b6dcd5.pdf (solarpowereurope.org)

Statista. (2024, July 9). *Europe: Biofuel production by country 2023*. https://www.statista.com/statistics/332510/biofuels-production-in-selected-countries-in-europe/#:~:text=In%202023%2C%20the%20production%20of,share%20of%20global%20biofuel%20production.

Sterner, M., & Specht, M. (2021). Power-to-gas and power-to-X—the history and results of developing a new storage concept. Energies, 14(20), 6594. https://doi.org/10.3390/en14206594

Strategic Energy Technology Plan Geothermal IWG. (2023, December). *Set-plan - deep geothermal IWG implementation plan - setis*. setis.ec.europa.eu. https://setis.ec.europa.eu/system/files/2021-04/Implementation%20plan%20on%20deep%20geothermal%20energy.pdf

Sutu, A. (2023, September 22). *Solar Heat Worldwide Report 2023 sheds light on European market growth*. Solar Heat Europe. https://solarheateurope.eu/2023/09/22/solar-heat-worldwide-report-2023-sheds-light-on-european-market-growth/#:~:text=Denmark%20leads%20the%20SDH%20market,(SHIP)%20plants%20in%20Europe.

Tapoglou, E., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny, O. G., Eulaerts, O., & Grabowska, M. (2022, November 15). *Clean Energy Technology Observatory: Ocean Energy in the European Union – 2022 Status Report on*

technology development, trends, value chains and markets. JRC Publications Repository. https://publications.jrc.ec.europa.eu/repository/handle/JRC130617

TEPPFA. (2020, February 21). *Benefits of plastic pipes - material of choice*. https://www.teppfa.eu/benefits-of-plastic-pipes-and-fittings/plastic-pipe-material-of-choice/

The Plastics Pipe Institute. (2023). *Plastic Piping Materials for Ground Source Geothermal Systems*. www.plasticpipe.org. https://www.plasticpipe.org/common/Uploaded%20files/1-PPI/Divisions/Building%20and%20Construction/Division%20Publications/Presentations/Plastic%20Piping%20for%20Geo%20Ground%20Loops_01-23.pdf

US Department of Energy. (2024). *Types of hydropower turbines | Department of Energy* . www.energy.gov. https://www.energy.gov/eere/water/types-hydropower-turbines

Verbund. (2024). Our power plants on Austria's waterways. www.verbund.com. https://www.verbund.com/en-at/about-verbund/power-plants/water-bodies#:~:text=country%20for%20hydropower.-,In%20Austria%2C%20around%20two%20thirds%20of%20the%20electricity%20comes%20from,have%20always%20been%20closely%20connected.

Wind Europe. (2023, May). *WindEurope's response to the European Commission's legislative proposals for Electricity Market Design reform* . windeurope.org. https://windeurope.org/wp-content/uploads/files/policy/position-papers/20230525-WindEurope-Market-Design-response.pdf

Xie, J., & Zuo, L. (2013). Dynamics and control of Ocean Wave Energy Converters. *International Journal of Dynamics and Control*, *1*(3), 262–276. https://doi.org/10.1007/s40435-013-0025-x

Zahraee, S. M., Shiwakoti, N., & Stasinopoulos, P. (2020). Biomass supply chain environmental and socio-economic analysis: 40-Years comprehensive review of methods, decision issues, sustainability challenges, and the way forward. *Biomass and Bioenergy*, *142*, 105777. https://doi.org/10.1016/j.biombioe.2020.105777

Zhang, T., Uratani, J., Huang, Y., Xu, L., Griffiths, S., & Ding, Y. (2023). Hydrogen liquefaction and storage: Recent progress and Perspectives. *Renewable and Sustainable Energy Reviews*, *176*, 113204. https://doi.org/10.1016/j.rser.2023.113204

INTERVIEW LIST

Number	Energy	Organisation	Name in the Report	Name
1	Solar Thermal	Solar Heat Europe	VC, Interview 1, 2024	Leopoldo Mico
2	Solar	Roof Installation SME	VC, Interview 2, 2024	Johannes Springinsfeld
3	Small Hydropower	EREF	VC, Interview 3, 2024	Dirk Hendricks
4	Small Hydropower	Kleinwasserkraft Österreich and EREF	VC, Interview 4, 2024	Paul Ablinger
5	Small Hydropower	UNIDO	VC, Interview 5, 2024	Eva Kremere
6	Hydrogen	Hydrogen Europe	VC, Interview 6, 2024	Maximilian Kuhn
7	Solar PV	Solar Power Europe	VC, Interview 7, 2024	Claire Morin
7b	Solar PV	Solar Power Europe	VC, Interview 7b, 2024	Thomas Garabetian
8	Hydrogen	CEN/CENELEC – Energy/Hydrogen	VC, Interview 8, 2024	**No consent given for name disclosure*
9	Solar PV	Committee Manager of ISO/TC 160	VC, Interview 9, 2024	Tom Stack
10	Biodiesel	European Biodiesel Board	VC, Interview 10, 2024	Eva Tormo
11	Hydrogen	CEN/CENELEC	VC, Interview 11, 2024	Marc-Antoine Carreira da Cruz
12	Geothermal	EGEC	VC, Interview 12, 2024	**No consent given for name disclosure*
13	Solar	ISO/TC 180 on Solar Energy	VC, Interview 13, 2024	**No consent given for name disclosure*
14	Ocean	CEO of CalWave Inc.	VC, Interview 14, 2025	Marcus Lehmann