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DELIVERABLE 1.3

Report on Regulation Framework Analysis

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Main authors:	Forrest Kluson and Christina Zinke
Project website address:	www.value4farm.eu

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Nature of the Deliverable		
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DATA	Data sets, microdata, etc.	
OTHER	Software, technical diagram, etc.	

Dissemination Level		
PU	Public, fully open and automatically posted online	X
SEN	Sensitive, limited under the conditions of the Grand Agreement	
CI	Classified information: RESTREINT UE (Commission Decision 2015/444/EC)	
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Lastly, thank you to Lucile Sever and the European Biogas Association for providing helpful informational reports for the literature review.

DISCLAIMER

It is important to stress that the policy information compiled in this report is not intended to represent a comprehensive overview of the policy landscape relevant to agrivoltaics and biogas/biomethane in the EU. The reference of relevant policy areas is restricted to agriculture, bioeconomy, and renewable energy in order to provide a preliminary overview of the overarching political and regulatory forces influencing current EU development in agrivoltaics and biogas/biomethane. The findings of the report are intended to inform VALUE4FARM partners in the upcoming Task 2.2 *Development of the agricultural protocols* and Task 2.3 *Comprehensive study for off-grid biomethane plants*.

A more extensive overview of relevant policies will be conducted iteratively in Task 4.4 *Elaboration of Policy Recommendations*, which will further examine the VALUE4FARM policy landscape outlined in this report. Research will include further literature review, expert interviews, and stakeholder surveys to investigate further policies relevant to not only agriculture, bioeconomy, and renewable energy but also research and development, industry, waste, environment, biodiversity, climate, etc. The projected outcome of Task 4.4 will be a detailed report for informing external stakeholders of good policy practices, regulatory and policy barriers, and policy recommendations for improving the uptake of agrivoltaics biogas/biomethane in the EU.

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EXECUTIVE SUMMARY

This report presents the outcome of Task 1.3 *Regulation Framework Analysis* in the VALUE4FARM project. The purpose of T1.3 is twofold: first, outline the dimensions of the policy landscape relevant to project demonstration value chains; second, review current sector development and policy frameworks relevant to the promotion of sustainable food production and renewable energy generation. Within the scope of the report, special attention is placed on (1) agrivoltaics, biogas/biomethane, and the VALUE4FARM model for coupling both technologies as a model value chain, (2) policy frameworks at the EU-level and national and regional levels in VALUE4FARM demonstration countries, and (3) the policy focus areas of agriculture, bioeconomy, and renewable energy.

Initially, background information is provided for the VALUE4FARM project, the methodological approach and aims of the regulation framework analysis, and the data sources used for collecting information.

Secondly, a conceptual outline is presented for the policy landscape associated with agrivoltaic and biogas/biomethane value chains. This section introduces the VALUE4FARM representative model for coupled agrivoltaic and biogas/biomethane production, outlining the sequential stages involved in the biomass value chain. Thereafter, the surrounding dimensions of the policy landscape are defined according to relevant types of policy instruments and the overarching environments in which agrivoltaic and biogas/biomethane value chains are positioned. The comprehensive framework outlines a concise yet thorough model of the intricate interplay of factors shaping VALUE4FARM demonstration value chains.

Thirdly, a literature review of the EU-level policy landscape presents the broad economic and political environments relevant to European agriculture, renewable energy, agrivoltaics and biogas/biomethane. Key EU figures and statistics are presented to provide a condensed overview of the state of European agriculture and energy sectors, as well as the general status quo, trends, and challenges of agrivoltaic and biogas/biomethane development. A final overview of EU polices outlines relevant agriculture, bioeconomy, and renewable energy policies and regulations.

Fourthly, further literature review presents the policy landscapes for the countries housing the VALUE4FARM demonstration sites, i.e., Denmark, Belgium, and Italy, as well as Poland, the location of a VALUE4FARM replication site (the policy landscape for the remaining replication site country of Iceland will be investigated in WP4). Designed to follow the structure of the previous EU-level policy landscape as much as possible, the provided sections present information on the national agricultural and renewable energy contexts, development of agrivoltaics and biogas/biomethane, as well as national and regional policy frameworks relevant to the uptake of both technologies. The provided information is intended to inform policy makers within the respective countries, and to guide the development of the agricultural protocols as part of WP2.

Finally, the collected information is organised into succinct, conclusive key findings regarding the outline of the VALUE4FARM policy landscape and the status quo of the agriculture and renewable energy policy landscapes for the EU at large, Denmark, Belgium, Italy, and Poland. Furthermore, final remarks emphasise the limitations of the collected literature review and reinforce its intended use in further policy analysis in upcoming WP4 tasks.

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LIST OF ABBREVIATIONS

AFIR – EU Alternative Fuels Infrastructure Regulation

BG - Biogas Policy Instrument (see Annex II - List of Identified Policy Instruments)

BM – Biomethane Policy Instrument (see Annex II - List of Identified Policy Instruments)

CAP – EU Common Agricultural Policy

CIC - Certificate of Release to Consumption of Biofuels

CHP – Combined Heat and Power

CNG – Compressed Natural Gas

CoO - Certificate of Origin

EAFRD - European Agricultural Fund for Rural Development

EAGF – European Agricultural Guarantee Fund

EBA – European Biogas Association

EC – European Commission

EGD – European Green Deal

ESR – EU Effort Sharing Regulation

ETD – EU Energy Taxation Directive

EU – European Union

EU ETS – EU Emission Trading System

FiP – Feed-in Premium

FiT – Feed-in Tariff

GDP – Gross Domestic Product

GHG – Greenhouse Gas

GoO - Guarantee of Origin

GSE – Italian Energy Service System Operator *(Gestore dei Servizi Energetici)*

GUDP - Green Development and Demonstration Program

GVA – Gross Value Added

IEA – International Energy Agency

JRC – EU Joint Research Centre

LNG – Liquefied Natural Gas

MFF – EU Multiannual Financial Framework

MiTe - Ministry of Energy Transition

NECP - EU National Energy and Climate Plan

NPF – EU National Policy Framework

O - Objective

OFMSW - Organic Fraction of Municipal Solid Waste

OMSW - Organic Municipal Solid Waste

PEP2040 - Poland's Energy Policy until 2040

PPA - Power Purchase Agreement

PV - Photovoltaic

RED – EU Renewable Energy Directive

RD&D - Research, Development and Demonstration

RRF – EU Recovery and Resilience Facility

RRP – National Recovery and Resilience Plan

R&D - Research and Development

TES - Total Energy Supply

UAA - Utilised Agricultural Area

VLIF - Flemish Agricultural Investment Fund *(Vlaams LandbouwInvesteringsFonds)*

WP – Work Package

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1. INTRODUCTION

1.1 AIM AND CONTEXT

The overall objective of the VALUE4FARM project is to demonstrate the effectiveness, sustainability, and replicability of three renewable-based local value chains based on biogas and coupling sustainable food production, and renewable energy generation in order to both contribute to the defossilisation of the agricultural sector and match local needs in terms of electricity, heat, mobility, residual bioresources, and land management. The overall objective is also complemented by four clear, realistic, measurable, and verifiable objectives (Os) outlined in Table 1.

Objective	Description
O1	Develop sustainable agricultural protocols, compatible with renewable energy production and farmers' specifications
O2	Propose a wide range of renewable energy production and storage technologies, meeting farmers' residues management, electricity, heat, and mobility needs
O3	Validate the sustainability and circularity of three renewable-based local value chains through demonstration
O4	Ensure the replicability and widespread use of the demonstrated overall value chains

Table 1. Objectives of VALUE4FARM project (Objectives supported by D1.3 are circled in red)

A key goal within the overall objective of VALUE4FARM is to create an overview of the policies that regulate and stimulate the uptake of value chains focused on combining agricultural and renewable energy production, with a specific focus placed on agrivoltaics and biogas/biomethane production, as these two technologies are an important part of the VALUE4FARM project. The created overview of the policy framework will map the current landscape of relevant policy instruments from European Union (EU), national, and regional levels, identifying good policy practices, regulatory barriers and opportunities, drivers, trends, future policies, and finally policy recommendations. Collected information will be used initially to inform VALUE4FARM internal partners in the development of agricultural and technological protocols and finally to advise external stakeholders, namely the target groups of farming communities, technology providers, policy makers, and public bodies in EU regions. The policy framework will directly support achieving O1 and O4 of the measurable objectives outlined in the VALUE4FARM project proposal (see Table 1)

This report describes the initial step in outlining the policy framework overview. The provided information focuses on presenting both a methodological outline of the VALUE4FARM policy landscape and an overview of European sectors and existing policy frameworks that are relevant to the uptake of value

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chains implementing agrivoltaics and/or biogas/biomethane production. It is important to note that this initial stage of the policy framework analysis does not provide a comprehensive overview of relevant policies, but rather a standardized structure of analysis with preliminary findings. The provided information is intended to provide political and regulatory insights that inform the design of VALUE4FARM value chain specifications within EU, national, and local policy frameworks. Furthermore, findings are intended to be used as a conceptual foundation for further iterative policy framework analysis within VALUE4FARM, informing the later development of defining good policy practices, regulatory barriers and opportunities, drivers, trends and future policies, and policy recommendations as part of Work Package (WP) 4.

The structure of the report is as follows: Chapter 2 outlines the scope of the regulation framework analysis, highlighting the conceptual bases for defining (1) a representative value chain model of the VALUE4FARM demonstrations, (2) the extent of the investigated policy landscape, and (3) the relevant policy instruments considered in the framework. Chapter 3 reviews the status of agriculture and renewable energy sectors in the EU. Chapter 4 examines development trends, potentials, and challenges of agrivoltaics and biogas/biomethane in the EU. Chapter 5 describes the prominent EU policies within agriculture, bioeconomy, and renewable energy. Chapter 6 outlines an overview of the relevant policy landscapes for the three VALUE4FARM demonstration sites, i.e., Denmark, Belgium, Italy, and one of the replication sites, i.e., Poland, outlining prominent agriculture and renewable energy sector developments and policies at the national and regional level. Chapter 7 provides final conclusions, outlining the limitations of the report and summarizing key findings from the collected information.

1.2 Approach

The collection and organisation of policies and regulations relevant to the value chains demonstrated in VALUE4FARM involves a multi-faceted, iterative methodology, where two stages of investigation are implemented (see Figure 1).

The findings outlined in this report pertain to the outcome of the first stage of investigation, Task 1.3 *Regulation Framework Analysis*, conducted during the first six months of the VALUE4FARM project. This stage focuses on conducting a literature review to create a preliminary overview of the policy landscape relevant to the VALUE4FARM value chains focused on agrivoltaics and biogas/biomethane production. The policies included within the framework range from EU, national, and regional levels, where data collection was conducted with contributions from the VALUE4FARM demonstration and replication site partners.

The second stage of investigation involves Task 4.4 *Policy Recommendations*, conducted from the 18th to the final (42nd) month of the project. This stage involves using the finding of this report to inform the further identification of good policy practices, regulatory barriers and opportunities, drivers, trends, and future policies in order to define policy recommendations for supporting renewable energy adapted to sustainable agriculture. The methodology for Task 4.4 includes further literature review building on the preliminary analysis performed in Task 1.3, supplementary expert interviews and stakeholder surveys, and collaborative meetings with VALUE4FARM partners.

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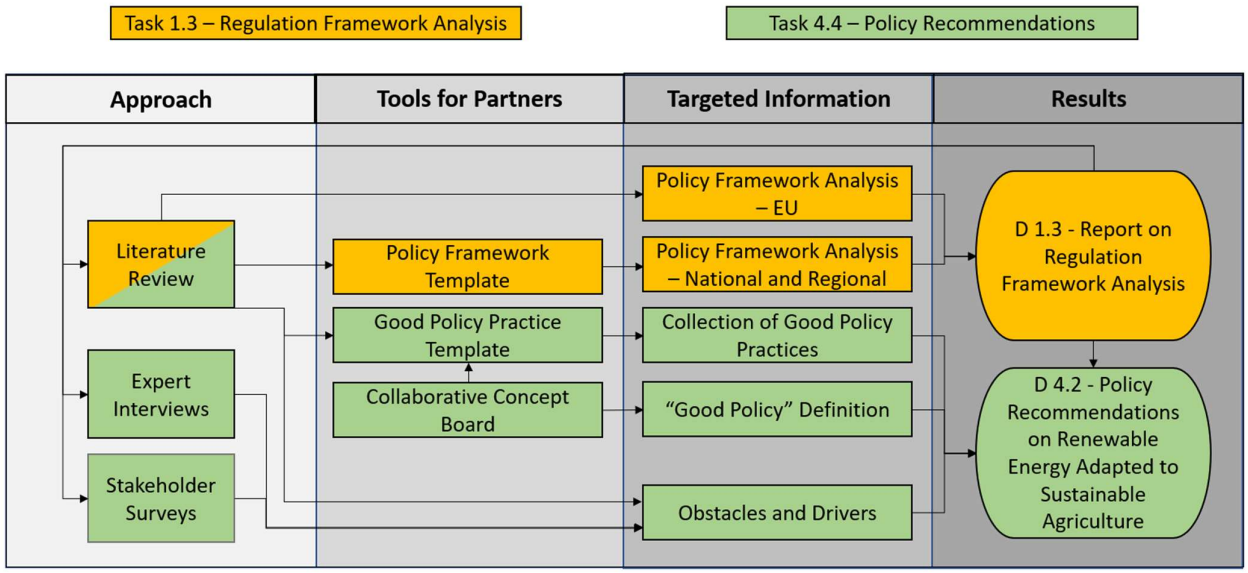

Figure 1. Flowchart outlining the methodological process steps of VALUE4FARM Task 1.3, Task 4.4, and their interrelationship. Theoretical basis sourced from (Zinke, 2023)

1.3 Data Collection

The literature review conducted for this report utilised various sources to collect information about relevant policies for value chains coupling sustainable food and renewable energy generation through agrivoltaics and biogas/biomethane. Notably, the initial review collected information from the existing reports of relevant EU projects in which members of the VALUE4FARM consortium participated, which was then complemented by additional EU project reports related to bioeconomy and renewable energies. At this stage of review, the S2BIOM[1], POWER4BIO[2], BRANCHES[3], and GREENMEUP[4] projects provided key insights into identifying both relevant policies and the structure of the policy landscape related to agrivoltaics and biogas/biomethane.

Additional information was collected from further reports, scientific articles, and databases from national and EU organisations related to the bioeconomy and renewable energy. The most relevant organisations for providing information included the European Statistical Office (Eurostat), the official website of EU law (EUR-Lex), International Energy Agency (IEA), and European Biogas Association (EBA). Furthermore, a key component of completing the literature review involved the collaboration with VALUE4FARM partners

[1] https://www.s2biom.eu/
[2] https://power4bio.eu/
[3] https://www.branchesproject.eu/
[4] https://www.greenmeup-project.eu/

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in order to collect policy information specific to the countries and regions of the project demonstration and replication sites. This information was collected through the use of a literature review guideline template, which can be found in Annex I - Literature Review Guideline Template.

2. OUTLINE OF VALUE4FARM POLICY LANDSCAPE

The coupling of sustainable food production and renewable energy generation creates value chains that are impacted by a vast array of policies with various degrees of influence (e.g., technical, socio-economic, environmental, etc.). The presented outline of the VALUE4FARM policy landscape refines the scope of mapping relevant policies by focusing on policies' relation to the sequential stages of the demonstrated VALUE4FARM value chains and the overall policy landscape associated with the uptake of agrivoltaics and biogas/biomethane. The following subsections provide the guiding framework for mapping relevant policies, i.e., (1) the representative biomass value chain model of the VALUE4FARM demonstrations, (2) the broad policy landscape influencing value chains that couple sustainable food production and renewable energy generation, and (3) the classification of relevant types of policy instruments for regulating and stimulating the VALUE4FARM value chains.

2.1 Model Value Chain for Coupling Agrivoltaics and Biogas/Biomethane Production

All three VALUE4FARM demonstration sites experiment with specified dimensions of value chains focused on producing biogas/biomethane and/or agrivoltaics, coupling sustainable food and renewable energy production. In Denmark, add-ons are implemented to the traditional biomethane pathway for answering the local specificities of large-scale farms. In Belgium, a pathway towards the better use of already-existing residual streams is demonstrated for the efficient production of electricity, heat, and fuel, thus answering mobility needs for small-scale farms. In Italy, hybridisation compatibilities are investigated towards the creation of an efficient off-grid biomethane plant.

Each demonstration site operates within the broad conceptual model of value chains implementing agrivoltaics and/or biogas/biomethane production; more information is available in the VALUE4FARM *Report on Demonstrations' Specifications* (Amaducci, 2024). Through modifying Pelkmans and Van Dael's schematic overview of biomass value chains (Pelkmans et al., 2016), Figure 2 provides an overview of (1) the stages of the VALUE4FARM biomass value chain model, (2) each stage's relation and interaction with one another, and (3) the specific characteristics of each stage. Notably, the model value chain is intended to operate within a renewable, local scale, promoting circularity through nutrient recovery.

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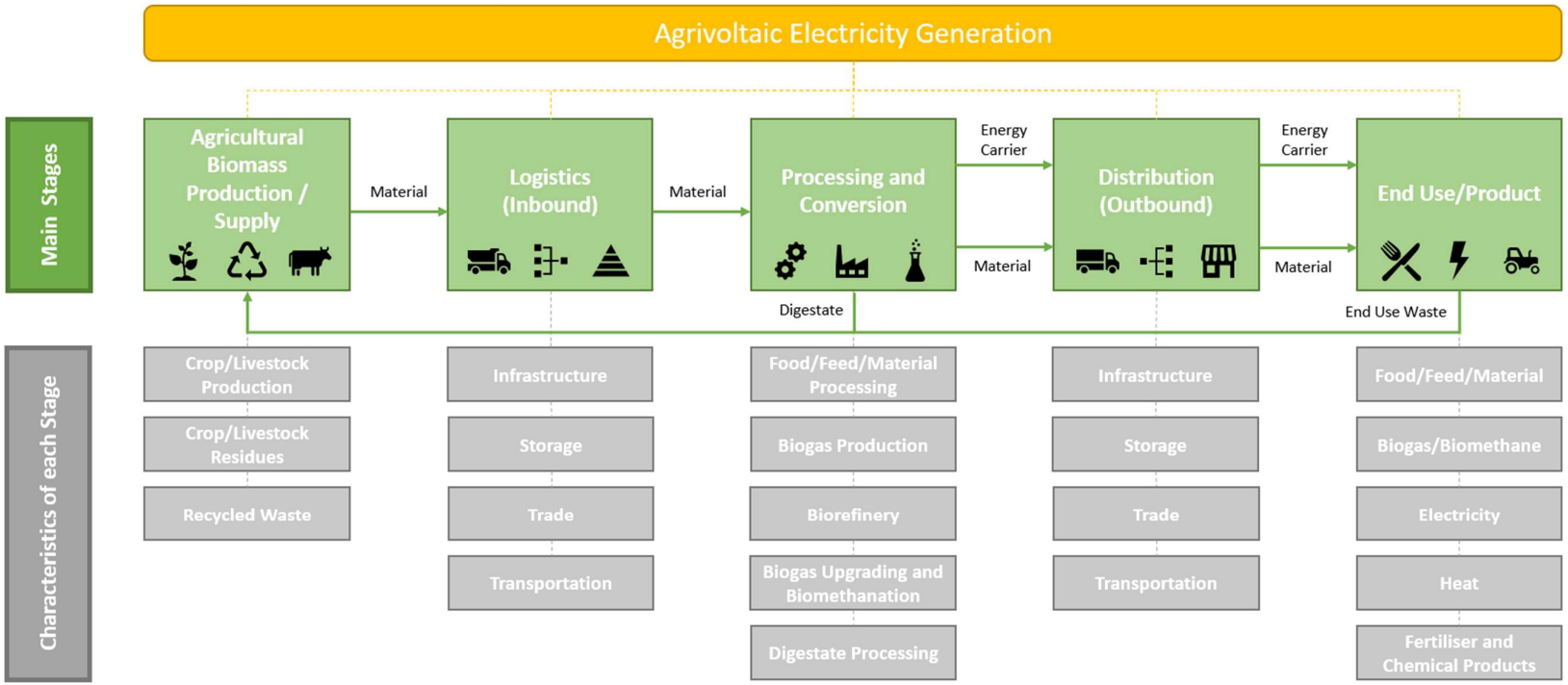

Figure 2. Schematic overview of the VALUE4FARM model value chain for coupled agrivoltaics and biogas/biomethane production. Modified from Pelkmans et al. (2016)

Importantly, the demonstrations in the context of VALUE4FARM only focus on value chains with **agricultural biomass** as the supply source. Within the biomass supply stage distinctions are made between the production of crops and livestock, biomass residues, and recycled biomass waste. Crop and livestock production refer to the primary biomass harvested from plants and animals for either food, feed, material, and energy purposes (e.g., vegetables, grain, meat, straw, etc.). Biomass residues refer to the secondary biomass produced by both animals during their lifespan (e.g., manure) and plants after their harvest (e.g., stalks, stems, roots, etc.), which is primarily used for further processing to make biofuel, biogas, and material products. Recycled waste refers to reutilised biomass sourced from both industrial processing and conversion (e.g., pulp, digestate, etc.), as well as the recycled end use products in the value chain. It is important to note that the designations of biomass products, residues, and waste can overlap based on the intended use of the biomass.

The **logistics** stage focuses on the management of biomass materials flows from the supply source to their conversion into a product or by-product. Important operations within this stage focus on the infrastructure needed for the inbound storage, trade, and transportation of the biomass.

The **conversion** stage is where produced or recycled agricultural biomass is processed into products, by-products, and energy carriers. Within VALUE4FARM, the focus of conversion processes is concentrated on the processing of non-food biomass, and investigated technologies are focused on three dimensions of biomass conversion:

i) the conversion of biomass to biogas and digestate,
ii) the refining and upgrading of biofuels to biomethane,
iii) the utilization of biomass, biogas, and/or biomethane for energy production, i.e., heat, electricity, engine combustion, etc.

Importantly, the by-products created in this stage, such as digestate, can also be redirected back into biomass production in order to create a circular nutrient cycle. A list of the relevant conversion technologies investigated in VALUE4FARM can be found in Table 2.

The **distribution** stage concentrates on the outbound logistics of created biomass products, by-products, and energy carriers to end users. Much like the inbound logistics stage, important operations within this stage focus on the infrastructure needed for the storage, trade, and transportation of the outbound products, by-products, and energy carriers. Infrastructure plays an especially important role in these operations, with various grid systems, transportation networks, and storage facilities being utilized to move energy carriers, i.e., biogas/biomethane, heat, and electricity.

The **end use** stage refers to the final utility of the products created in the value chain. This stage also includes the recycling of end use materials or waste back into the biomass supply of the value chain. A list of the products and end uses relevant to the focus of VALUE4FARM can be found in Table 2.

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Value Chain Products and End Uses	Renewable Energy Technologies
Agricultural Crops and Livestock	Photovoltaic Panels (PV)
Biogas/Biomethane	Anaerobic Digestion
Electricity	Microturbines
Heat	Combined Heat and Power (CHP) Units
Digestate	Biogas Upgrading
Organic Chemicals and Fertilizers (e.g., RENURE)	Biomethanation
	Green Biorefineries
Refined Biomass (e.g., protein concentrate, brown juice, biomass pulp/fibre)	Biogas Tractors

Table 2. List of the products and technologies relevant to the VALUE4FARM demonstration value chains

Finally, agrivoltaic electricity generation complements the biomass value chain. This energy generation is created simultaneously during agricultural biomass production and can be directed into electrical grid systems, which can theoretically contribute energy to any stage of the value chain.

2.2 Framework for Policy Landscape

The policy landscape relevant to VALUE4FARM includes the policies that affect the development of European agrivoltaic, biomass, and biogas/biomethane value chains, as well as the policies affecting the broad uptake of agrivoltaics and biogas/biomethane in the EU. Through modifying the systematic bioeconomy landscape of Elbersen et al. (2020), the model for the VALUE4FARM policy landscape focuses on identifying which policies affect the specific stages of demonstration value chains and which policies are relevant to the bioeconomy, renewable energy, socio-economic, and environmental systems in which the value chains exist (see Figure 3).

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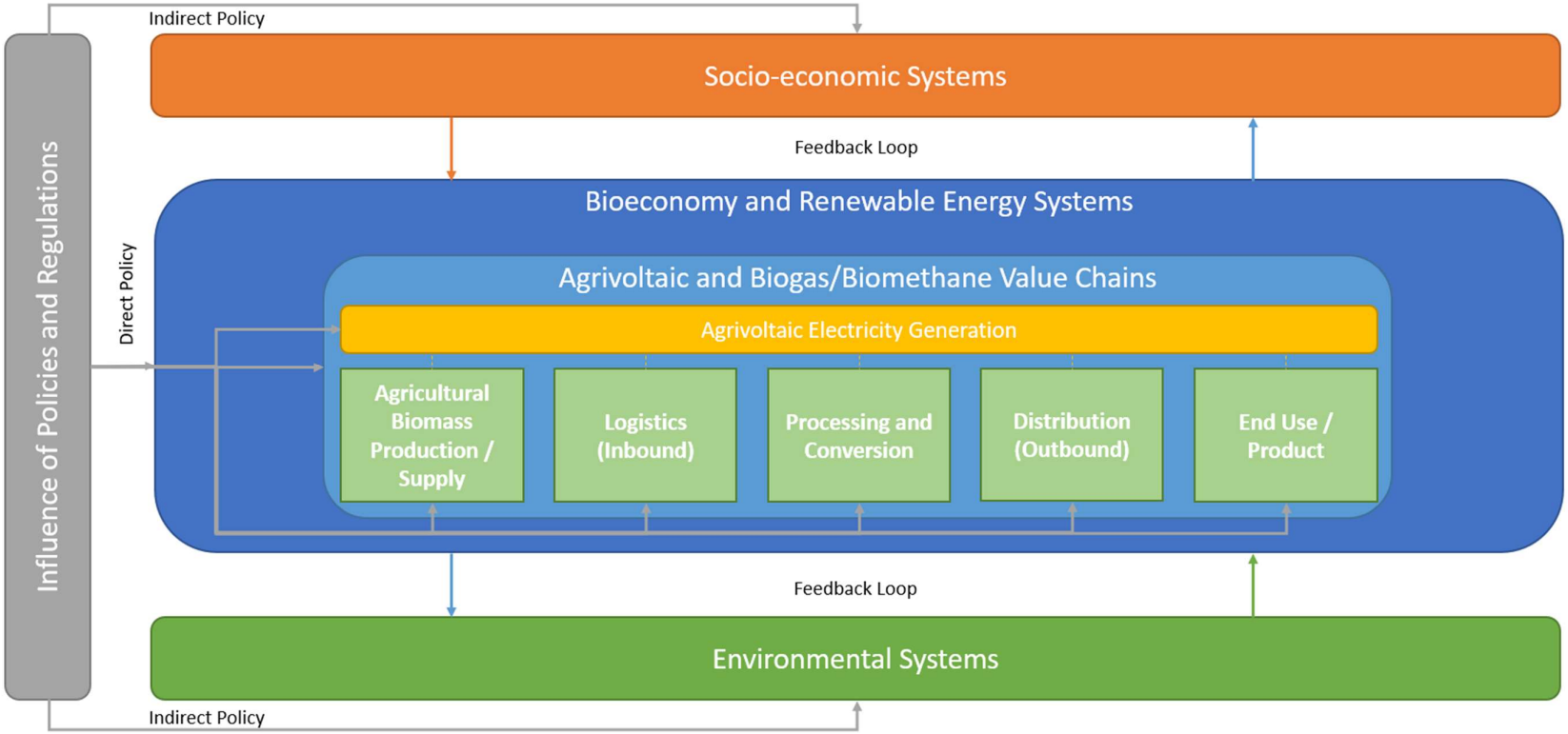

Figure 3. Graphical representation of the policy landscape relevant to agrivoltaics and biogas/biomethane. Based on Elbersen et al. (2020) and van Berkum et al. (2018)

The core of the policy framework (see bright blue box in Figure 3) focuses on the model value chain of agrivoltaics and biogas/biomethane production investigated in the VALUE4FARM demonstration sites (see Subsection 2.1). Within this level of analysis, policies are identified according to their influence over agrivoltaic electricity generation and the specific stages of biomass value chains, i.e., biomass production/supply, inbound logistics, processing and conversion, outbound distribution, and end use.

Surrounding the activities of the VALUE4FARM value chain lies the larger systems of the bioeconomy and renewable energies (see dark blue box in Figure 3), which define the environments in which agrivoltaic and biogas/biomethane value chains operate. Specific considerations within the larger systems include food/feed, industrial, and enabling environments, as well as business services and consumer characteristics. The food and industrial environments refer to conditional requirements such as the labelling, quality, access, and promotion of food/feed and manufactured products. The enabling environment includes functional conditions such as transportation networks, infrastructure, research and development (R&D), existing regulations, and institutional design. Business services include those services that are necessary for the successful development of bio-based or renewable energy-based business models, such as knowledge, financial, technological, and innovation support. Consumer characteristics are the factors influencing individual customers within the marketplace, such as how much time they have, their preferences, how informed they are, and their level of purchasing power. This level of the policy landscape can be understood as the focus on how regulations and policies are determining the status quo of the bioeconomy and renewable energy systems.

The activities of bioeconomy and renewable energy systems and the value chains operated within them also place impacts on larger socio-economic and environmental systems (see orange and green boxes in Figure 3). The conditions of these systems create feedback loops that directly and indirectly affect value chains associated with producing, processing, distributing, and consuming biomass materials and renewable energy. Socio-economic systems refer to the dynamics of markets, policies, science and technology, and social organisations; which respectively determine feedback loops between market volatility and trade, political support and conflict, technological productivity and intensification, and social empowerment and income. Environmental systems refer to the larger biophysical contexts of land availability and soil quality, climactic conditions, biodiversity, and the usage of fossil fuels, minerals, and water. Feedback loops associated with these contexts include the dynamics between land use and soil degradation, climate change and climate conditions, biodiversity loss and ecosystem services, emissions and fossil fuel use, resource scarcity and mineral usage, and water pollution and water usage, respectively.

Figure 3 graphically outlines the dynamics of the policy landscape in order to provide an overview of how policies and regulations can be used to influence the many factors involved in agrivoltaics and biogas/biomethane production. Direct policy measures are considered to be those directly affecting the value chain, i.e., agrivoltaic electricity production, biomass production/supply, inbound logistics, processing and conversion, outbound distribution, and end use, as well as the bioeconomy and renewable energy systems, i.e., the business services, consumer characteristics, and enabling, food, and industrial environments. Indirect policy measures focus on regulating the dynamic between the bioeconomy and renewable energy systems with the conditions of socio-economic and environmental systems. Extended elaborations of the theoretical framework used for defining the policy landscape of agrivoltaic and biogas/biomethane value chains, i.e., the bioeconomy, renewable energy, socio-economic, and environmental systems, can be found in van Berkum et al. (2018) and Elbersen et al. (2020).

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2.3 Relevant Policy Instruments

Building on the definitions defined in the POWER4BIO (Elbersen et al., 2020) and BRANCHES (Zinke, 2023) projects, the organisation of relevant policy instruments within the VALUE4FARM policy landscape is defined according to the following policy categories:

i) regulatory;
ii) economic/financial;
iii) voluntary action;
iv) informational/advisory;
v) market-based signaling;
vi) visionary/strategical instruments.

Hard instruments, i.e., binding policies that force compliance, exist within regulatory and economic/financial instruments. Soft instruments, i.e., non-binding or voluntary policies, are present in economic/financial, voluntary initiative, informational/advisory, market-based signalling, and visionary/strategical instruments. A full overview of policy instrument classifications is listed in Table 3.

Furthermore, in regard to renewable energy, and more specifically biogas and biomethane, Lorin et al. (2023) organize supportive policy instruments into five categories.

- National Visions and Targets: Government strategies, plans, or roadmaps that outline a framework for planning public policy measures, defining binding and non-binding renewable energy targets. Such policy tools allow industry actors to understand policy perspectives and plan investments.
- Direct Investment and Production Support: Government assistance for renewable energy producers provided through either financing capital expenses (investments) or subsidising production costs. These support mechanisms are intended to provide developers with investment security and help stimulate renewable energy markets to reach an economy of scale. Prominent examples of production support include the following policy mechanisms.
    - Feed-in Tariffs (FiT): A guaranteed payment above the market rate to renewable energy producers for energy fed into the grid, typically at a fixed rate over a set period of time.
    - Feed-in Premiums (FiP): Unlike a FiT, where producers receive a fixed price for their produced energy, FiP provides producers of renewable energy with a premium on top of the market price for each unit of energy they generate and feed into the grid. This support mechanism allows the market price to fluctuate, with producers receiving a supplementary payment to ensure a certain level of revenue, ultimately allowing more flexibility in aligning incentives with market dynamics while still encouraging renewable energy generation.
    - Net-metering Schemes: A billing arrangement that allows producers of renewable energy, primarily solar PV systems, to receive credit for the electricity they generate but do not

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consume immediately. This credit can then be used to offset electricity consumption from the grid during periods when their renewable energy generation does not meet on-site demand. Such schemes are designed to encourage the adoption of renewable energy technologies by providing financial incentives and reducing the upfront costs for consumers.

    - Tender Schemes: The allocation of pre-defined volumes of subsidies through an auction system, where different levels of FiTs are offered for a plant project with the lowest projected cost of production, ultimately creating the incentive for developers to produce the most efficient energy production models in order to receive financial assistance.

- Indirect Production Support: Regulatory and financial incentives for supporting the inputs and outputs of renewable energy generation. In regard to biogas/biomethane production, indirect production support refers to policies supporting the sourcing of biomass feedstock for energy producers, as well as the further products resulting from biogas/biomethane production (e.g., electricity, digestate, and biogenic CO_2).
- Demand-side Incentives: Measures designed to stimulate the consumption of renewable energy, through either tax incentives or obligatory mandates, which generally raise awareness for renewable energy and improve consumers' perception of it. Tax incentives involve the reduction or exemption of tax obligations, creating an immediate financial interest compared to conventional, non-renewable energy sources, which can therefore spur rapid growth in renewable energy consumption. Examples of obligatory mandates include obligations for renewable energy shares or CO_2 emission reductions from energy producers or public authorities.
- Regulations Enabling Market Access: Policy mechanisms that establish renewable energy sources' access to energy grid systems and their traceability in the energy marketplace. Prominent examples of polices include government-mandated Guarantee of Origin (GoO) schemes or industry-initiated green certificate registries that track the source of the power bought by companies and energy suppliers in the market back to the power plant that produced it. In regard to biomethane grid access, important measures include the right for producers to inject into the gas grid, defined and achievable specifications regarding biomethane quality, investment cost-sharing with grid operators, and the ensured year-round capacity for grid injection.

An overview of relevant policy instrument examples within the bioeconomy policy landscape, i.e., biomass production/supply, inbound logistics, processing and conversion, outbound distribution, end use, bioeconomy, and socio-economic and environmental systems, can be found in the POWER4BIO report *An overview of suitable regional policies to support bio-based business models* (Elbersen et al., 2020). An overview of good practices for biomethane supportive policies can be found in the GREENMEUP report *Overview of production routes and end-uses of renewable gases and existing policy frameworks in advanced European and Mission Innovation countries* (Lorin et al., 2023).

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Category of Policy Instrument		Examples
Hard Instruments	Regulatory	• Regulations • Directives • Quotas • Targets • Obligatory Standards and Licenses • Permitting Instruments
	Economic/Financial	• Taxes • Financial Grants • Subsidies • Loans • Tradable Certificates • Tax/Financial Incentives • Tendering Schemes • Research & Development Funds
Soft Instruments	Voluntary Action	• Codes of Good Practice • Self-regulation • Non-obligatory Financial Incentives • Networks
	Informational/Advisory	• Education/Awareness Programs
	Market-based Signalling	• Information Provisions (Labels, Traceability, Voluntary Certification Schemes)
	Visionary/Strategical	• Strategies • Action Plans • Official Recommendations

Table 3. Categories and examples of policy instruments. Sourced from Elbersen et al. (2020) and Zinke (2023).

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3. OVERVIEW OF EU AGRICULTURE AND RENEWABLE ENERGY SECTORS

3.1 AGRICULTURE

In 2020, the post-Brexit EU (EU-27) bioeconomy represented ca. 4.9% of the EU's GDP (€665 billion) and employed ca. 8.3% of the total EU workforce (17.2 million jobs). Within the bioeconomy, the agricultural sector employs more than half of the workforce (8.7 million employees) and is responsible for the second largest share of value added (€191.2 billion), second to the manufacturing sector of food, beverage, and tobacco. Figure 4 provides a visual comparison of employment and value added between agriculture and the other sectors within the EU bioeconomy. (Tamošiunas et al., 2022).

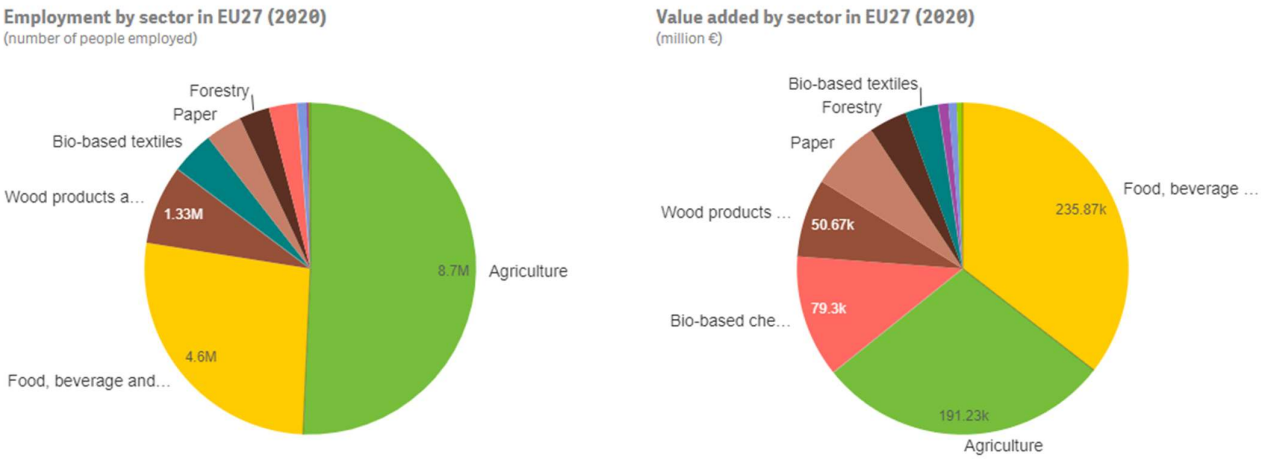

Figure 4. Dual graphs for employment and value added by sector in the bioeconomy. EU27, 2020. Source: (Tamošiunas et al., 2022)

Agriculture in the EU follows the same two dominant trends that define the development of the EU bioeconomy, i.e., the overall workforce is shrinking and the overall value added is growing. Specifically, from 2008 to 2020 employment in EU agriculture shrunk by 2.7 million people, and annual value added grew by €32.1 billion. The decrease in employees and increase in added value are attributed to gains in labour productivity in all sectors (Tamošiunas et al., 2022).

In the broad context of all EU member countries, the contribution of agriculture to employment is relatively low, ca. 4.2% of total EU employment. However, agriculture employment rates vary widely across Europe, where many regions are more reliant on agricultural economies. Figure 5 shows the 2020 EU regional

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employment rates for the agriculture, forestry, and fishing sector, that of which agriculture substantiates ca. 93% of all employment. The sector maintains high employment rates in eastern and southern EU countries, particularly within regions in Poland, Romania, Greece, and Spain. (Eurostat, 2023d).

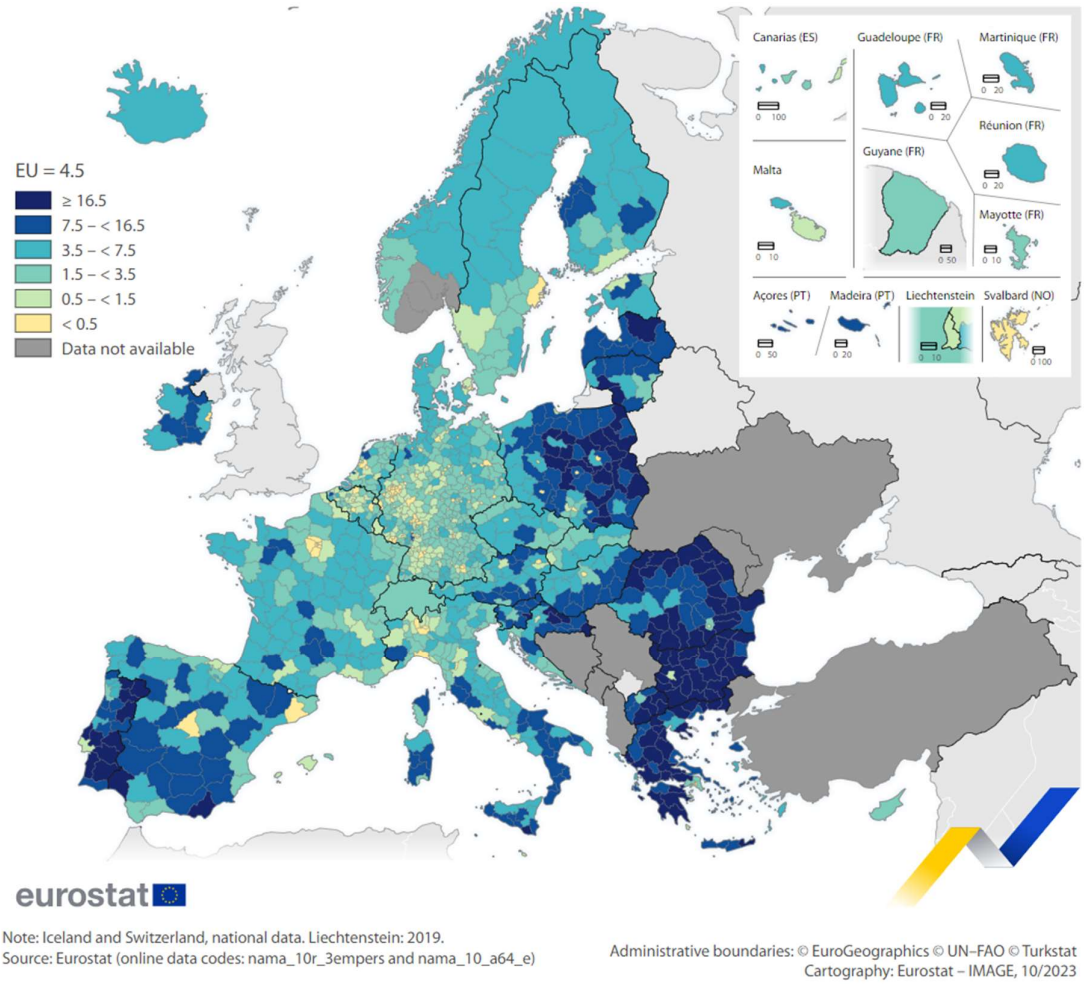

Figure 5. Employment in the agriculture, forestry, and fishing sector (% of total employment, by NUTS 3 regions). EU, 2020. Source: (Eurostat, 2023d)

As of 2020, the land area for agricultural production across all EU countries, also known as the total utilised agricultural area (UAA), was recorded to be 157.4 million ha, mostly comprised of arable land (62.3%), along with permanent grassland (30.5%), permanent crops (7.1%), and kitchen garden (0.1%). From 2010 to 2020, recorded data reveals the following observable trends:

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i) there is a significant reduction of 1.5 million ha in the total UAA, which was mostly sourced from 2 million fewer ha of permanent grasslands;
ii) the amount of UAA used for arable land remained steady, with only an increase of ca. 0.1 million ha;
iii) there was an observed increase of 0.5 million ha in permanent crops, revealing how cropping patterns are moving towards less permanent grassland and more permanent crops.

Figure 6 outlines the 2020 agricultural land use distribution of UAA amongst all EU countries. Notably, only six EU countries (France, Spain, Germany, Poland, Romania, and Italy) hold two-thirds (68.6%) of all the EU's current UAA (Eurostat, 2023b).

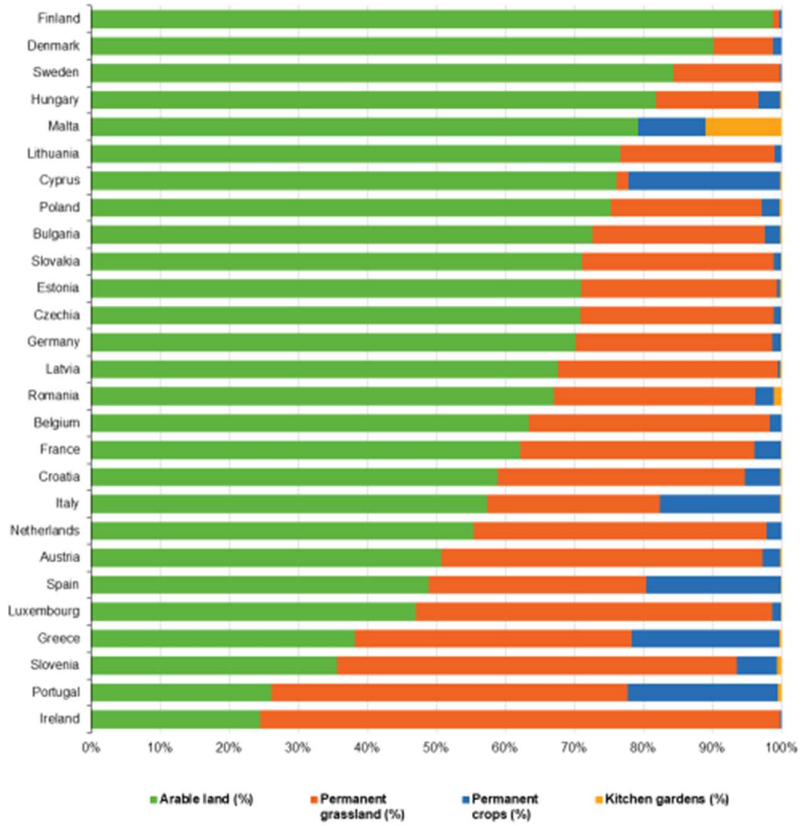

Figure 6. Type of agricultural land use (& share of utilised agricultural area). EU countries, 2020. Source: (Eurostat, 2023b)

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3.2 Energy Mix

Energy consumption in the EU is defined by dependency on fossil fuel imports. In 2021, the EU produced around 44% of its own energy and imported 56% of its energy needs from outside countries, the vast majority of which were fossil fuels, i.e., crude oil and petroleum products (64%), natural gas (25%) and solid fossil fuels (6%). In contrast, primary energy production in the EU was comprised largely by renewable energy (41%), followed by nuclear energy (31%), solid fuels (18%), natural gas (6%) and crude oil (3%) (see Figure 7). The 2021 total energy mix in the EU, meaning the range of energy sources available, consisted of 34% crude oil and petroleum products, 23% natural gas, 17% renewable energy, 13% nuclear energy and 12% solid fossil fuels (European Commission. Eurostat, 2023). A visualisation of the EU total energy supply is displayed in Figure 8.

The EU's high energy dependence rate (approx. 56% in 2021), meaning the extent to which the EU economy relies upon fossil fuel imports in order to meet its energy needs, has remained relatively stable since 2000 (see Figure 9). This dependency hinders the EU's ability to transition away from fossil fuels to renewable energy (European Commission. Eurostat, 2023). Notably, the EU sanctions imposed on Russian fuel imports as a consequence of the 2022 Russian invasion of Ukraine have caused energy market disruptions that subject EU energy imports to constant change. As of the third quarter of 2023, measurable reductions have been recorded in EU energy imports as supply chains continues to move away from Russian sources (Eurostat, 2023a). However, the long-term effects that the transition away from Russian fuel imports have placed on the EU energy import market are not yet determinable.

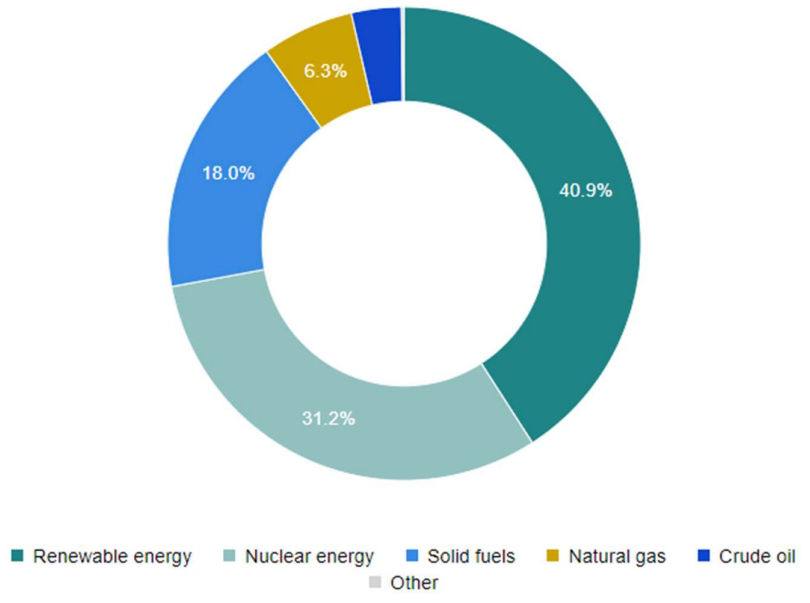

Figure 7. Share of total primary energy production by energy source. EU, 2021. Source: (Eurostat, 2022c)

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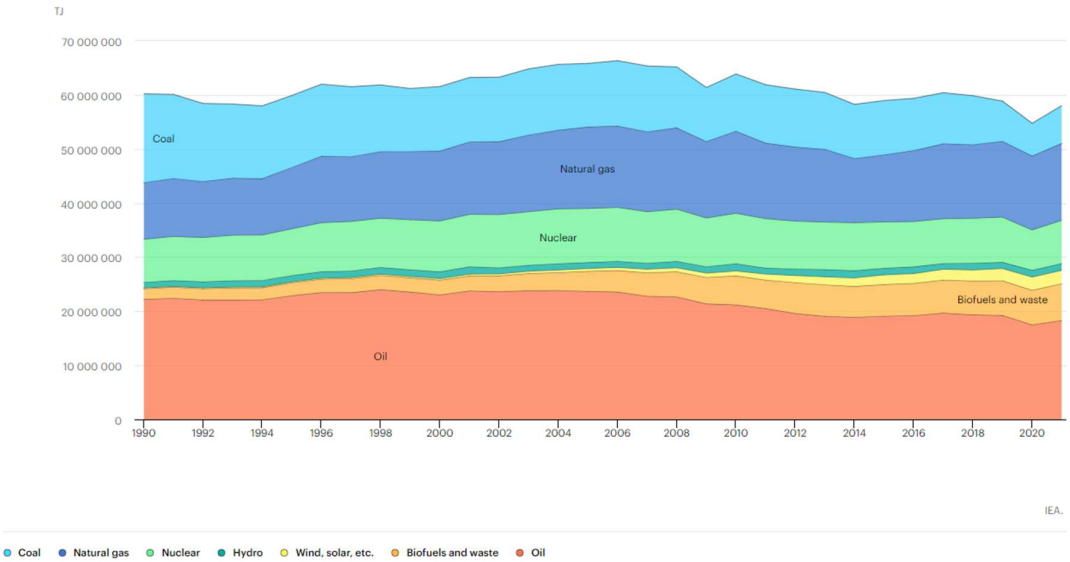

Figure 8. Total energy supply by source. EU, 1990-2021. Source: (IEA, 2023c)

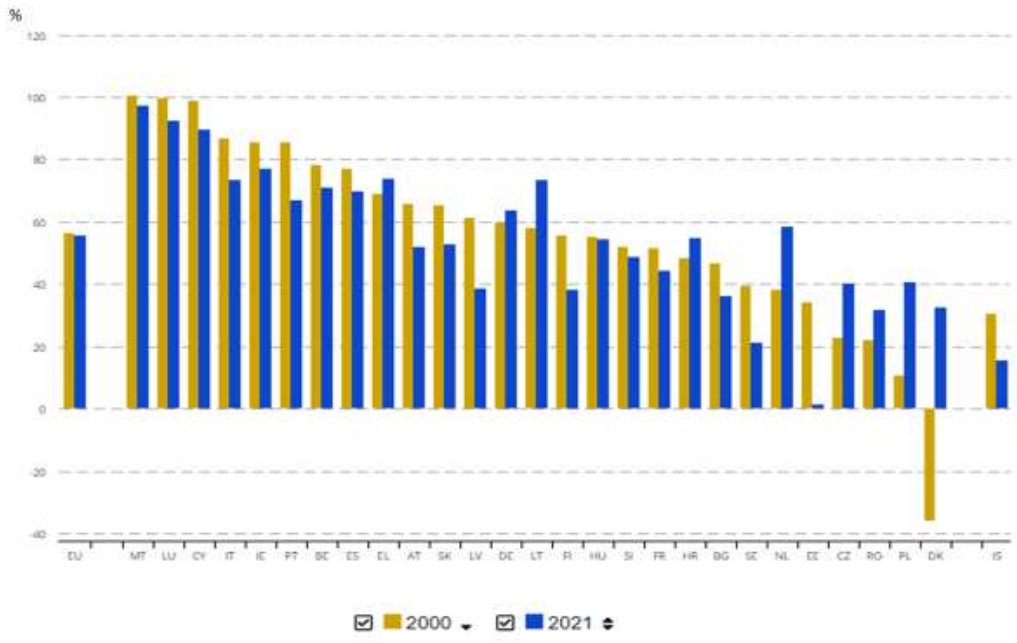

Figure 9. Energy dependency rate (% of net imports in gross available energy, based on terajoules). EU, 2000 compared with 2021. Source: (Eurostat, 2022b)

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3.3 Renewable Energy

In 2022, 23% of the energy consumed in the EU was sourced from renewable energy. This achievement is a result of the steadily rising consumption of renewable energy, due to increased renewable energy production within the EU (Eurostat, 2022b). As seen in Figure 10, most renewable energy is consumed as electricity, comprising over 40% of total electricity consumption. Heating and cooling follow thereafter, with ca. 25% of consumption being sourced from renewable sources. Lastly, the transportation sector still maintains a low integration of renewable energy, with ca. 10% of energy consumption sourced from renewables. Notably, the share of renewable energy sources within electricity production is comprised first of wind with 386,867 GWh, followed by hydro (374,850 GWh), solar photovoltaics (PV) (158,588 GWh), and biofuels (149,795 GWh) (IEA, 2023c).

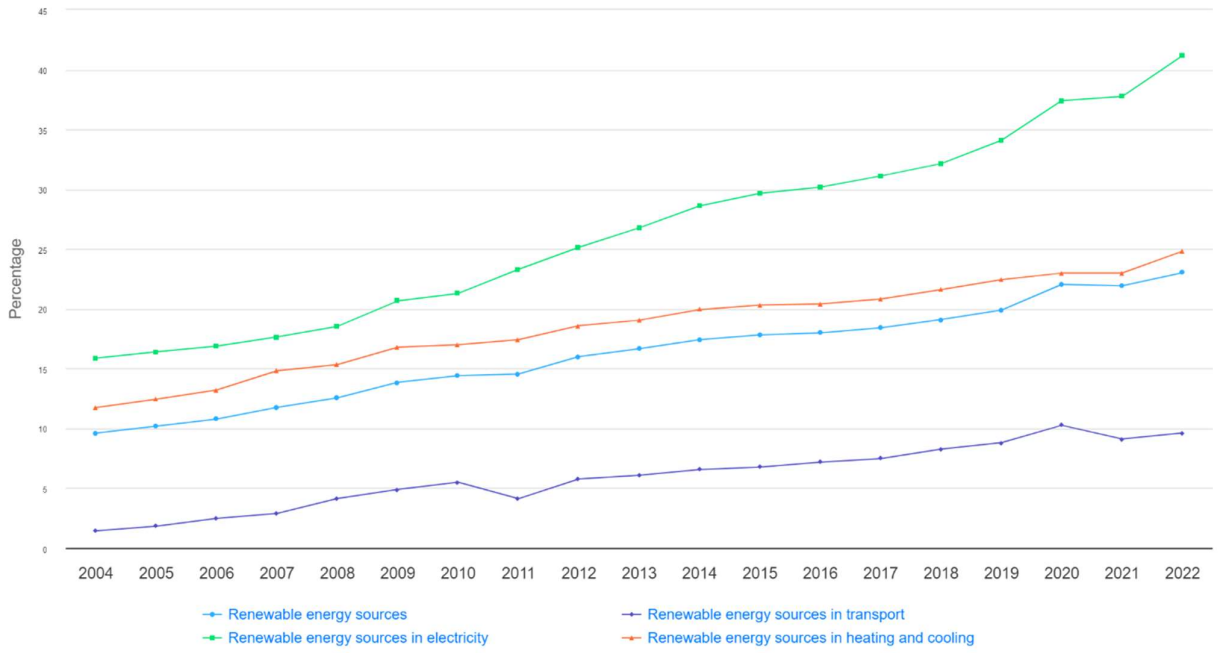

Figure 10. Share of energy consumption from renewable sources. EU, 2004-2022. Source: (Eurostat, 2022c)

In 2021, the total energy supply (TES) of non-combustible renewable energy sources reached 4,324,832.81 TJ, and TES of combustible renewable energy sources reached 6,203,573.73 TJ. Figure 11 and Figure 12 show the respective compositional breakdown of energy sources within both non-combustible and combustible renewable energy sources (Eurostat, 2022a).

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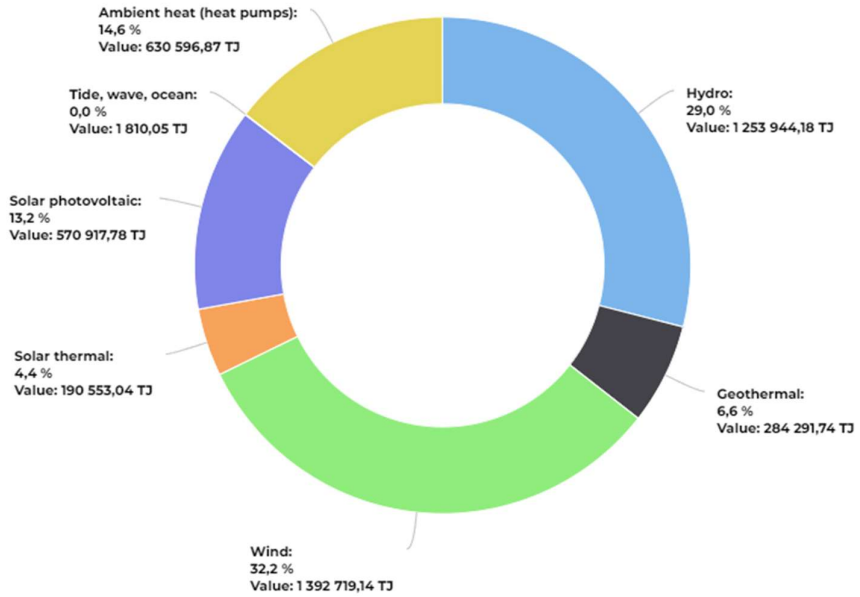

Figure 11. Total energy supply of non-combustible renewable energy by energy sectors. EU, 2021. Source: (Eurostat, 2022a)

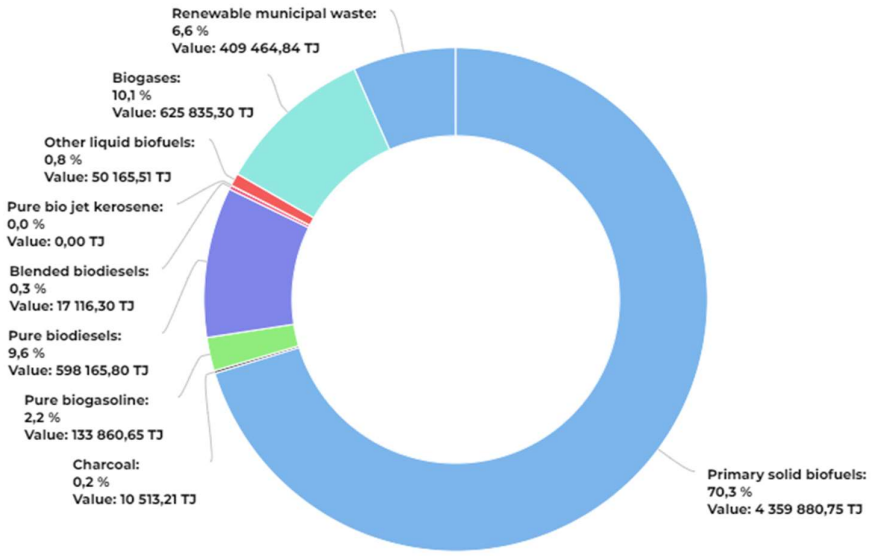

Figure 12. Total energy supply of combustible renewable energy by energy sectors. EU, 2021. Source: (Eurostat, 2022a)

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3.4 Energy in Agriculture

As seen in Figure 13, agriculture does not comprise a large share of the energy consumed in the EU. In 2021, energy consumed in agriculture and forestry equalled 1,183,812 TJ, equaling less than 3% of the ca. 43,000,000 TJ of energy consumed. Contrarily, agriculture is a sizable contributor to renewable energy production in the EU, comprising 11.5% of all renewable energy production in 2021 (Eurostat, 2023c). Nonetheless, as presented by Figure 14, renewable energy sourced from agriculture comprises only a minor share of the total primary energy production in the EU.

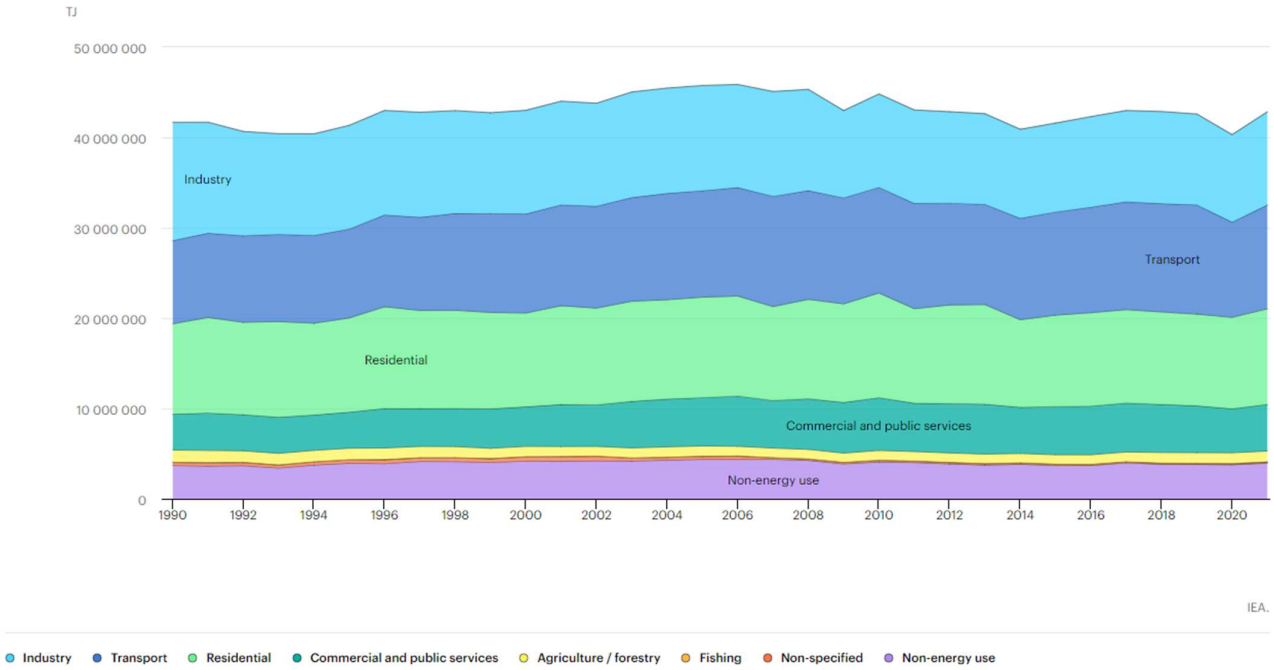

Figure 13. Total final consumption (TFC) by sector. EU27, 1990-2021. Source: (IEA, 2023c)

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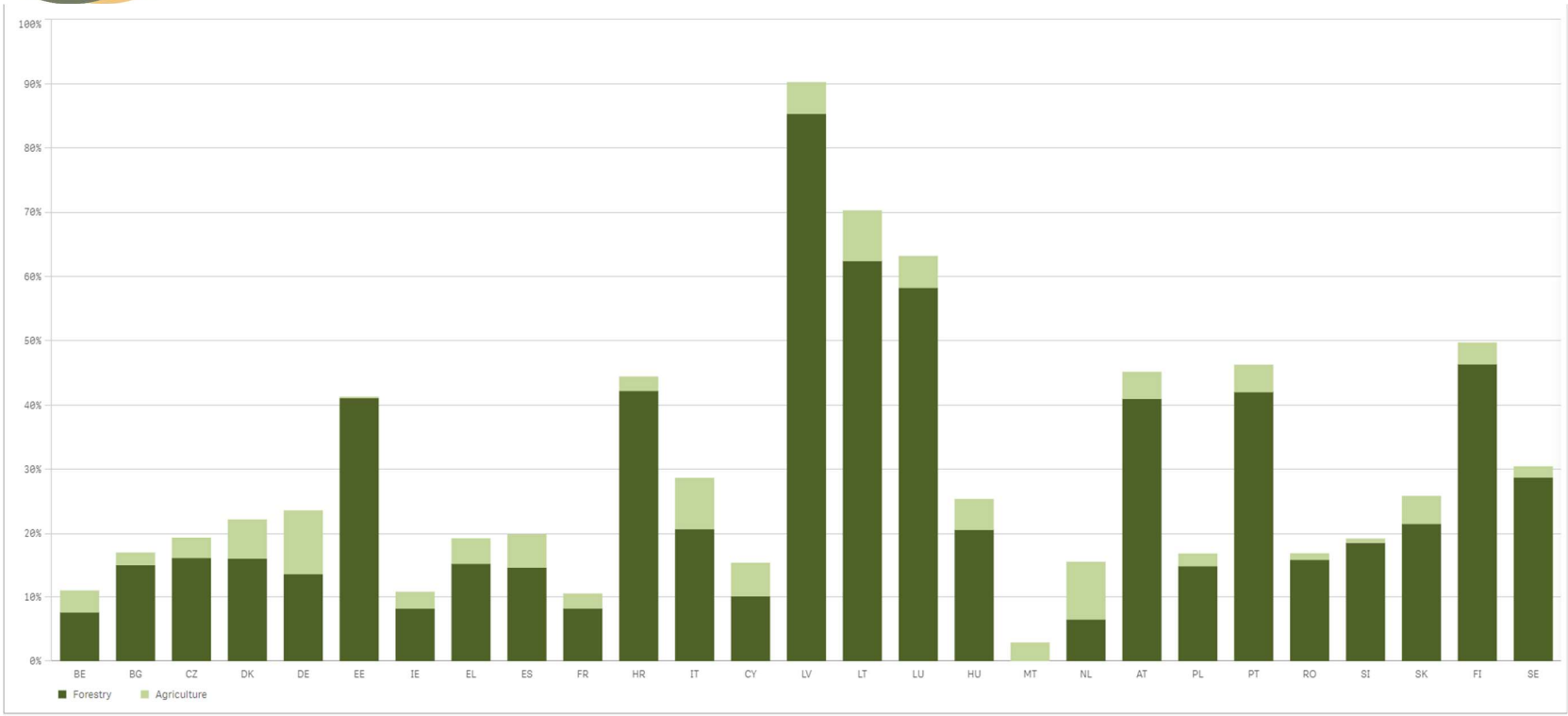

Figure 14. Production of renewable energy from agriculture and forestry as a share of total primary energy production. EU, 2021. Source: (Eurostat, 2023c)

4. OVERVIEW OF EU AGRIVOLTAIC AND BIOGAS/BIOMETHANE LANDSCAPE

4.1 AGRIVOLTAICS

The concept of agrivoltaics, i.e., the integration of farming activities and the production of electricity using PV panels on the same piece of land, was proposed for the first time in 1982 by Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems (ISE), who realised that a massive expansion of PV would increase the consumption of agricultural land. In the EU, agrivoltaics is still a vastly underdeveloped industry, with most existing systems being used on a pilot or experimental scale. However, the interest for the deployment of agrivoltaic systems has increased rapidly over the last years, mainly due to the increasing need for electricity production and the limited availability of new land due to the increasing global food demand. According to the EU Joint Research Centre (JRC), there are a growing number of efforts integrating agrivoltaics into R&D, industry, associations, and conferences in the EU (Chatzipanagi et al., 2023). Within R&D, there have thus far been substantial efforts in investigating the crop yields, maximalization of electricity production, economic and landscape planning, and supporting IT tools in agrivoltaic systems. Notable projects and developed tools are listed below.

- SYMBIOSYST: Horizon Europe project focusing on combining energy supply issues with the needs of the agricultural sector.
- HyPErFarm: Horizon Europe project focusing on investigating business models and innovative technologies and crop production methods in order to promote agrivoltaic uptake.
- AgriPV Webtool: Tool designed by KU Leuven in the HyPErFarm project (KU Leuven, 2022), which allows users to define input parameters of theoretical agrivoltaic systems in order to determine outputs such as installed power, energy yield, relative crop yield, levelized cost of electricity (LCoE), and others.
- AgriPV Modeling Tool: Tool under development by the Institute for Solar Research at the German Aerospace Center *(Deutschen Zentrums für Luft- und Raumfahrt - DLR)* for the determination of the best economic agrivoltaic design combining the maximum agricultural yield and the maximum power generation simultaneously (DLR, 2022).
- AgriPV Suitability Map: ArcGIS tool developed by the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) in Italy, which utilizes geophysical, technical, environmental, economic, socio-political and landscape criteria to identify the ideal areas for the deployment of agrivoltaic systems in Italy, as well as their potential capacity.

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Prominent actors in the EU related to agrivoltaics include:

i) Fraunhofer Institute for Solar Energy Systems (ISE);
ii) Associazione Italiana Agrivoltaico Sostenibile (AIAS);
iii) France Agrivoltaïsme;
iv) European Photovoltaic Solar Energy Conference and Exhibition (EU-PVSEC);
v) Agrivoltaics World Conference;
vi) Agrivoltaics Europe Conference;
vii) SolarPower Europe – Land Use and Permitting Workstream.

Challenges and Potential

Crops in agrivoltaic systems can use water more efficiently, better tolerate high temperatures, and be more protected from potentially damaging weather events. Therefore, there are claims that agrivoltaic systems that are implemented and managed effectively, especially in hot and dry regions, can be a tool for resilience against climate change. However, it is first important to increase the knowledge about the technology so that its potential benefits do not become a vehicle for speculators.

Furthermore, the development of agrivoltaics in the EU is entangled in political, technical, and technological challenges (Chatzipanagi et al., 2023). Notably, one of the main challenges is the lack of a well-defined, EU-standardized definition for agrivoltaics. Thus far, only certain EU member states, such as Germany, Italy, and France, have working definitions, and the lack of a harmonized definition at the EU-level leaves a potential for 'greenwashing' agrivoltaic terminology, i.e., using conventional PV installations on agricultural lands and characterising the systems as agrivoltaic, since they would satisfy the partial requirements, and a change in agricultural land designation after the installation of agrivoltaic systems, which can create legal challenges for farmers and ineligibility for agricultural subsidies from their respective national Common Agricultural Policy (CAP) Strategic Plans. Other noteworthy challenges and considerations for limiting the risks associated with the development of agrivoltaics in the EU include:

i) A lack of references, specified targets, or financial support for agrivoltaics in most EU member state CAP Strategic Plans;
ii) agricultural land price change as a result of agrivoltaic system installation;
iii) a lack of public awareness and acceptance from farmers and rural communities for agrivoltaics;
iv) complicated procedures for the permitting and connecting of agrivoltaic systems to electrical grids;
v) further research needed for defining optimal technical parameters for maximizing electricity production with minimal impact to crop yield and biodiversity;
vi) keeping farmers and the rural communities at the centre of agrivoltaic promotion, ensuring economic benefit and security of property;
vii) spatial planning for identifying/classifying the potential agricultural land for agrivoltaic deployment;
viii) ensuring the continuation of agricultural activity in agrivoltaic systems;

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ix) further developing R&D and pilot schemes;
x) ensuring training and technical support;
xi) boosting public awareness and acceptance with respect to all the above-mentioned actions.

Through addressing the identified challenges, the potential of agrivoltaics in the EU is significant, offering a sustainable and innovative solution that can contribute to both energy production and agricultural productivity, while supporting broader environmental and sustainability goals. Detailed potential regarding the technology is outlined in the following points.

- Substantial Power Generation Potential: Multiple studies, have calculated that with agrivoltaic systems land use efficiency is increased by at least 20% and up to 100%, compared to systems in which agricultural activities and PV installation are separated. Many researchers have also claimed that in agrivoltaic systems the production of PV electricity is integrated with agricultural crops in a synergistic way, where effective management will not only minimize reductions in crop yields, but in certain contexts will even increase them. As seen in Table 4, covering just 1% of the UAA in the EU with agrivoltaic systems could yield ca. 944 GW (assuming a 0.6 MW/ha power to land area ratio). This capacity is approximately half of what traditional ground-mounted PV systems could produce (around 1,809 GW) and about five times more than the EU's installed capacity in 2022.
- Contribution to European Green Deal Goals: Agrivoltaics aligns well with various policies within clean energy, energy transition, sustainable agriculture, food security, biodiversity, rural development, and research & innovation. In regard to renewable energy targets, it is projected that agrivoltaics would require only ca. 0.4% of UAA coverage to reach EU Solar Energy Strategy 2025 PV targets (ca. 330 GW) and ca. 0.8% of UAA coverage to reach Solar Energy Strategy 2030 PV targets (ca. 730 GW).
- High Energy Yield: The energy yield from agrivoltaics is notably higher than that of biofuels. For example, an agrivoltaic installation with a power density of 0.6 MW/ha can provide ca. 2400 GJ/ha, which is significantly higher than the energy yield of biofuels, which range from 30 to 100 GJ/ha (Strapasson et al., 2020).
- Dual Land Use for Food and Energy Production: Agrivoltaics offers an efficient solution to the growing need for electricity production and the limited availability of new land, due to increasing global food demand. The simultaneous production of electricity and food on the same land is particularly relevant in the context of land scarcity and sustainable land management strategies.

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	10 % area coverage		5 % area coverage		1 % area coverage	
	Area (ha)	Potential (GW)	Area (ha)	Potential (GW)	Area (ha)	Potential (GW)
Utilised agricultural area	15 726 214	*9 436*	7 863 107	*4 718*	1 572 621	*944*
Arable land	9 793 456	*5 876*	4 896 728	*2 938*	979 346	*588*
Permanent grassland and meadow	4 877 482	*2 926*	2 438 741	*1 463*	487 748	*293*
Permanent crops	1 026 726	*616*	513 363	*308*	102 673	*62*
Market gardens	28 577	*17*	14 289	*9*	2 858	*2*

Table 4. Technical potential for installed capacities of agrivoltaic systems for the UAA and the different land area subcategories in the EU, with different area coverage percentages (Based on 0.6 MW/ha power to land area ratio). Source: (Chatzipanagi et al., 2023)

4.2 Biogas and Biomethane

In contrast with agrivoltaics, biogas and biomethane production in the EU is a more established industry. Nevertheless, it is a small, underdeveloped, and still growing market within EU gas consumption. According to the EBA, annual production of biogas and biomethane has steadily increased from the 2010s into the 2020s, with the vast majority of output being sourced from biogas (Lorin et al., 2023). Figure 15 outlines this trend, showing biogas and biomethane reaching 196 TWh in 2021.

Figure 15. Combined biomethane and biogas production (TWh). EU, 2011-2021 Source: (Lorin et al., 2023)

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As seen in Figure 15, current trends show that the production of biogas in the EU is largely stagnating but biomethane is growing rapidly, showing an increase of 20% from 2020 to 2021. Correspondingly, the number of biomethane production plants continues to grow across Europe. In 2021, biomethane production plants totaled 1067, representing an increase of 184 plants compared to 2020. European countries such as France, the Netherlands, Italy, Switzerland, and the UK are prominent examples of the growing prioritisation of biomethane production, and countries such as Denmark, Sweden, and Estonia now report more biomethane production than biogas without upgrading. Figure 16 shows the 10 European countries with the highest biomethane production in 2020.

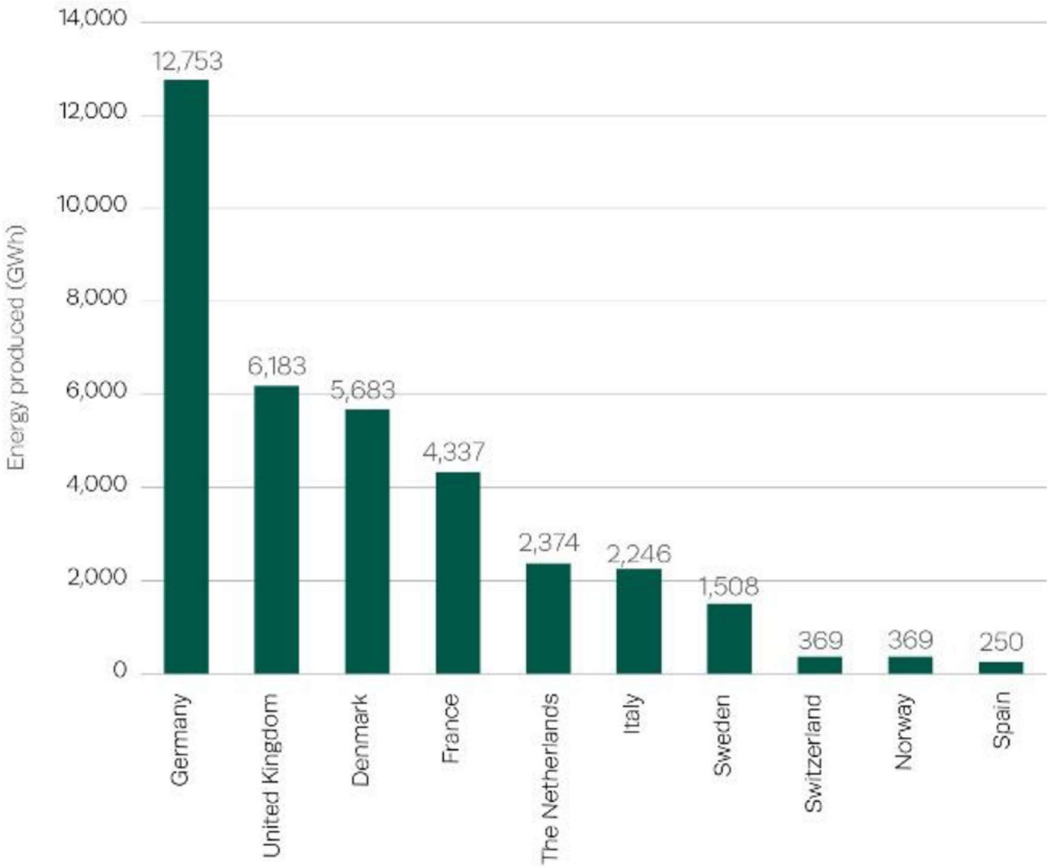

Figure 16. Biomethane production per country in descending order (GWh). Top 10 European countries, 2020. Source: (Lorin et al., 2023)

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Biogas production in Europe is largely comprised of anaerobic digestion plants using organic waste sourced from either agriculture, sewage, organic municipal solid waste (OMSW), industrial wastewater or solid waste, or landfills. The majority of biogas and biomethane production in Europe is sourced from agricultural plants, accounting for 64% of the total production. For biogas production, the second biggest source is landfill (14%). For biomethane production, the second biggest source is OMSW (11%). The distribution of biogas upgrading technology amongst biomethane plants in Europe is comprised of membrane separation (47%), water scrubbing (17%), chemical scrubbing (12%), pressure swing adsorption (10%), physical scrubbing (2%), and cryogenic separation (1%). There is no data concerning the upgrading technologies for 11% of European biomethane plants (Lorin et al., 2023).

Challenges and Potential

Biomethane is a more versatile energy carrier than biogas, able to be utilized in all end-uses of natural gas, i.e., transport, industry, power, and heating. Currently, trends show an emphasis being put on biomethane production in the European renewable gas market, with high energy supply and demand growth potentials and current technological capacities expected to amplify development in the coming decade (Sulewski et al., 2023). Findings from Prussi et al. (2019) and Scarlat et al. (2018) emphasize the potential of the expansion of the biomethane sector, with forecasted EU production values respectively showing potentials of 18 billion m^3 per year in 2030 mainly based on improvements to existing biogas plants, and 16 billion m^3 per year in 2030 sourced solely from manure sources.

The overall transition from biogas-focused to biomethane-focused renewable gas production will contribute to the EU's renewable energy targets, carbon neutrality goals, and energy security. However, there are many considerations regarding biogas and biomethane production and the transition will face technical, economic, regulatory, and infrastructural challenges. Key considerations include the following points.

- Transition from Energy Crops to Agricultural Biomass Residues: The majority of European biogas and biomethane production is sourced from agricultural production, where bioenergy crops cover 10 million ha (2.4%) of the total land area in the EU (Strapasson et al., 2020). In 2019, waste and residue feedstocks were used in almost 65% of EU biomethane plants compared to 40% in 2012 (Wouters et al., 2020). Future biogas and biomethane production will need to continue to transition away from bioenergy crops towards biomass residues in order to promote circularity in value chains and avoid competition with agriculture food production.
- Biomass Feedstock Quality and Availability: The efficiency and reliability of biogas production is heavily dependent on the quality of biomass feedstocks and the consistency of biomass value chains. Sourcing a consistent supply chain of suitable feedstock is vulnerable to market competition which can raise costs and limit availability. Furthermore, sourcing feedstock based on biomass residues creates varied biogas production efficiencies, which requires adaptable production technologies for maximising production yields (Scarlat, Dallemand, & Fahl, 2018).

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- High Production Costs: The production and upgrading of biogas to biomethane are associated with high capital and operational costs. This can make biomethane less competitive compared to fossil fuels without adequate financial incentives or support mechanisms (Sulewski et al., 2023).
- Biomethane Infrastructure: Infrastructure for the production, storage, distribution, and utilization of biomethane is crucial for successful deployment and market uptake, especially in the transport sector. Infrastructure fragmentation and the high costs of infrastructure development can limit the accessibility and use of biomethane (Prussi et al., 2021). According to the EBA, 58% of the active biomethane plants in Europe are connected to the distribution grid, 19% are connected to the transport grid, 9% do not have a grid connection, and no information is available for the remaining 14% (Lorin et al., 2023). Further infrastructural development is necessary for biogas upgrading facilities, refueling stations, and biomethane integration into natural gas grid systems.
- Policy Support: National Policy Frameworks (NPFs) in EU member states set targets for 2020-2030 to promote alternative fuels, including biomethane. However, challenges such as infrastructure fragmentation and high costs need to be addressed through a coherent set of supporting initiatives (Prussi et al., 2021).
- Pricing and Subsidy Reliance: The sustainability benefits of biogas and biomethane are often not recognized in its value, making biomethane more expensive than natural gas and therefore dependent on subsidies. Improvements in biogas upgrading technologies are necessary to make biomethane more economically viable and move away from subsidized support.
- Research and Technological Improvement: Continued research and innovation is necessary to improve the development and deployment of efficient and cost-effective technologies for biogas upgrading to biomethane. Furthermore, the diversity in the biogas production and upgrading technologies requires substantial investments in R&D to optimize processes and ensure their adaptability to different feedstocks and production scales (Prussi et al., 2019).
- Investment Barriers: The economic viability of biomethane projects is often challenged by high initial capital costs, uncertain and fluctuating market conditions, and the need for ongoing financial incentives to make projects feasible. The profitability of biomethane production is highly dependent on national support schemes, which vary significantly across the EU. This variability can create uncertainty for investors and hinder the growth of the biomethane market.
- Sustainability: Biomass feedstock, particularly the use of energy crops, have the potential to create negative environmental impacts, competition with food production, and land use changes. Therefore, it is imperative to ensure that biomass feedstock is sourced in an environmentally sustainable manner, without contributing to deforestation or biodiversity loss (Bušić et al., 2018). Since 2021, regulation of the sustainability of EU-produced biomethane is overseen by the European Renewable Gas Registry (ERGaR), which facilitates the certificate of origin (CoO) scheme, in accordance with the EU renewable energy directive, for the cross-border trade of biomethane.

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5. OVERVIEW OF EU POLICIES IN AGRICULTURE, BIOECONOMY, AND RENEWABLE ENERGY

The EU has an extensive framework of policies across all sectors[5] which promote sustainability and advance economic transitions away from fossil fuels towards renewable energy sources. Many of these polices also contain provisions which relate to agrivoltaics, biogas, and biomethane. The following subsections provide an overview of the prominent agriculture, bioeconomy, and renewable energy policies which determine the binding and non-binding legal norms for EU member states to adopt into their own national laws.

5.1 Strategies and Plans

European Green Deal

The European Green Deal[6] (EGD) is a framework of policy initiatives approved by the European Commission (EC) in 2020. The overarching objective is focused on steering the EU towards a sustainable, inclusive, and climate-neutral economy by 2050. Central to the initiative is the commitment to decouple economic growth from resource use and substantially reduce greenhouse gas (GHG) emissions, thereby positioning the EU as a global leader in sustainable development and climate action. Notably, the EGD itself is not a binding instrument, but a general strategy. Its intent is to provide a guideline for the revision and updating of EU laws and regulations to support the eight policy focus areas for making a sustainable and climate-neutral economy in the EU. The policy focus areas in the EGD include:

i) increasing the EU's climate ambition for 2030 and 2050;
ii) supplying clean, affordable, secure energy;
iii) mobilising industry for a clean and circular economy;
iv) building and renovating in an energy and resource efficient way;
v) a zero-pollution ambition for a toxic-free environment;
vi) preserving and restoring ecosystems and biodiversity;
vii) Farm to Fork: a fair, healthy and environmentally friendly food system;
viii) accelerating the shift to sustainable and smart mobility.

[5] https://commission.europa.eu/strategy-and-policy/policies_en?page=0
[6] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

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The Fit for 55[7] legislative package is a specific set of legislative proposals in the EGD aimed at implementing the EU's climate targets for achieving the intermediary goal of 55% less GHG emissions by 2030. It outlines the regulatory and policy frameworks necessary to guide the EU towards these targets, highlighting the interconnectedness of environmental policy with socio-economic dimensions within the EU. The package is seen as a critical step for the EU to achieve the broader objectives in the EGD, as it encompasses a broad range of measures, from the revision of the EU Emissions Trading System to new targets for renewable energy and energy efficiency, among others. Nevertheless, both the Fit for 55 package and the EGD receive criticism for being highly ambitious but still a fragile regulatory project, with clear tensions between the vision promoted by the EGD and the available regulatory tools (Chiti, 2022).

The implementation of the goals and targets outlined in the EGD is also supported by a network of strategies, plans, directives, and regulations. Prominent policies in the framework of the EGD which are relevant to the development of agrivoltaics and biogas/biomethane in the EU are included in the following subsections.

Common Agricultural Policy

The Common Agricultural Policy[8] (CAP) is a policy framework and funding mechanism that supports the EU agricultural sector. According to the EC, the main aims of the CAP are:

i) support farmers and improve agricultural productivity, ensuring a stable supply of affordable food;
ii) safeguard EU farmers to make a reasonable living;
iii) help tackle climate change and the sustainable management of natural resources;
iv) maintain rural areas and landscapes across the EU;
v) foster rural economies by promoting jobs in farming, agri-food industries, and associated sectors.

The organizational structure of the CAP is divided into two pillars: direct payments and rural development. The direct payments pillar provides income support in the form of subsidies for farmers, which are intended to provide income stability. Financing is sourced from the European Agricultural Guarantee Fund (EAGF) and comprises the vast majority of CAP financing for EU agriculture. The rural development pillar focuses on supporting long-term sustainability and environmental objectives in rural economies. It is funded by the European Agricultural Fund for Rural Development (EAFRD) and supports projects related to environmental conservation, agri-environmental schemes, and rural infrastructure.

[7] https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
[8] https://agriculture.ec.europa.eu/common-agricultural-policy_en#:~:text=The%20common%20agricultural%20policy%20(CAP,and%20keeps%20rural%20areas%20vibrant.

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As of 2023, EU countries implement the CAP through CAP Strategic Plans[9], the individual, decentralized agricultural policy plans for EU member states that are based on the EU-level objectives in the CAP 2023-2027[10]. According to the EC, national CAP Strategic Plans are defined according to the following points.

- National Responsibility: Each EU member state is required to develop a CAP Strategic Plan, which serves as the main framework for implementing CAP policies at the national level.
- National Objectives: Member states are expected to set their own national objectives and targets within the framework of EU-wide CAP objectives, allowing for greater adaptability to regional and local needs, conditions, and priorities.
- Policy Choices: Member states can make policy choices within certain parameters established by EU regulations. Policy choices can include decisions on the distribution of direct payments, the allocation of funds to specific CAP measures, and the design of eco-schemes.
- Conditionality: CAP strategic plans include a conditionality mechanism, which links a portion of direct payments to compliance with specific environmental and climate standards. Member states must ensure that farmers meet these standards to receive full direct payments.
- Eco-Schemes: Member states are required to allocate a certain percentage of their direct payment budget to eco-schemes, which are designed to incentivise environmentally friendly farming practices. Member states have flexibility in defining the specific eco-schemes they offer to farmers.
- Monitoring and Reporting: Member states are responsible for monitoring the implementation of their CAP strategic plans and reporting regularly to the EC on their progress. The EC assesses the plans and may provide feedback and recommendations.
- Performance and Accountability: The success of each member state's CAP Strategic Plan is evaluated against performance indicators and targets in environmental sustainability, climate change mitigation and adaptation, economic viability, social and territorial cohesion, innovation and knowledge transfer, and administrative efficiency and simplification. Member states are held accountable for achieving their stated objectives, and funding may be adjusted accordingly.
- Public Consultation: Member states are encouraged to involve stakeholders, including farmers, agricultural organizations, and environmental groups, in the development of their CAP Strategic Plans. Public consultation is seen as an essential element to ensure that the plans reflect the needs and priorities of various stakeholders.
- European Commission Approval: Once a CAP Strategic Plan is developed, it must be submitted to the EC for approval. The EC assesses if the plan complies with EU regulations and objectives.
- Multiannual Financial Framework: The financing of CAP measures is determined through the EU's Multiannual Financial Framework (MFF). Member states receive allocations from the MFF based on their CAP strategic plans.

[9] https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_en?prefLang=de
[10] https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en

The CAP 2023-2027 framework outlines ten EGD-aligned objectives for national CAP Strategic Plans to follow.

1. Fair income for farmers.
2. Increase competitiveness.
3. Improve the position of farmers in the food chain.
4. Climate change action.
5. Environmental care.
6. Preservation of landscapes and biodiversity.
7. Support for generational renewal.
8. Vibrant rural areas.
9. Protect food and health quality.
10. Foster knowledge and innovation.

Farm to Fork Strategy

Introduced in 2020, the EU Farm to Fork Strategy[11] outlines a vision and a set of objectives and priorities for transforming the EU's food system to be more sustainable, healthy, and environmentally friendly. As a component of the EGD, it serves as a roadmap for future legislative and regulatory actions and proposes a legislative framework for sustainable food systems (FSFS) in the realms of agriculture, food production, and food consumption within the EU. According to the strategy, the main areas for proposing legislation include:

i) ensuring sustainable food production and food security;
ii) stimulating sustainable food processing, wholesale, retail, hospitality, and food services practices;
iii) promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets;
iv) reducing food loss and waste;
v) combating food fraud along the food supply chain;
vi) research, innovation, technology and investments;
vii) advisory services, data and knowledge sharing, and skills.

[11] https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

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Bioeconomy Strategy

The EU's updated 2018 Bioeconomy Strategy[12] is a comprehensive framework aimed at promoting the potential of biological resources to foster sustainable economic growth and innovation. The updated version of the strategy focuses more on aligning bioeconomy development with international climate policy like the United Nations (UN) 2015 Paris Agreement, 2030 Agenda, and Sustainable Development Goals (SDGs), as well as new EU policy priorities. Primary objectives include the promotion of a circular and sustainable bioeconomy, the enhancement of Europe's competitiveness in bio-based industries, and the reinforcement of the EU's commitment to addressing societal challenges, such as climate change and resource scarcity. Several key policy areas include:

i) development of innovative bio-based industries;
ii) sustainable management of natural resources;
iii) establishment of a supportive regulatory framework;
iv) encouragement of research and investment in bioeconomy-related activities;
v) collaboration between the public and private sectors;
vi) enhancement of international partnerships to ensure global relevance and impact.

The Bioeconomy Strategy Action Plan[13] is the implementation tool for harmonising competition between different biomass sectors (e.g., food, feed and industrial application). It contains 14 concrete actions that focus on strengthening and scaling up the bio-based sectors, unlock investments and markets, deploying local bioeconomies rapidly across the whole of Europe, and understanding the ecological boundaries of the bioeconomy.

According to the *EU Bioeconomy Strategy Progress Report* (European Commission, 2022b), notable advancements in achieving the objectives of the Bioeconomy Strategy include:

i) an increasing number of national and regional bioeconomy strategies promoting cross-sectoral cooperation, sustainability principles, and investment in bioeconomy innovation;
ii) progressed bioeconomy development in Central and Eastern European countries, which have received significant EU funding contributions and organisation of new communication networks;
iii) increasing development in the mobilisation of private investments and research and innovations in food and other bio-based industries;
iv) a strong position fore the EU in the global market for bio-based chemicals and materials.

[12] https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/bioeconomy-strategy_en
[13] https://op.europa.eu/en/publication-detail/-/publication/775a2dc7-2a8b-11e9-8d04-01aa75ed71a1

According to the EC report *Bioeconomy strategy development in EU regions* (Haarich & Kirchmayr-Novak, 2022), the expansion of regional bioeconomy strategies is more common and more developed in EU14 countries than in widening ones (see Figure 17). Therefore, there is still a need for comprehensive regional bioeconomy policies, especially in widening countries and lagging regions.

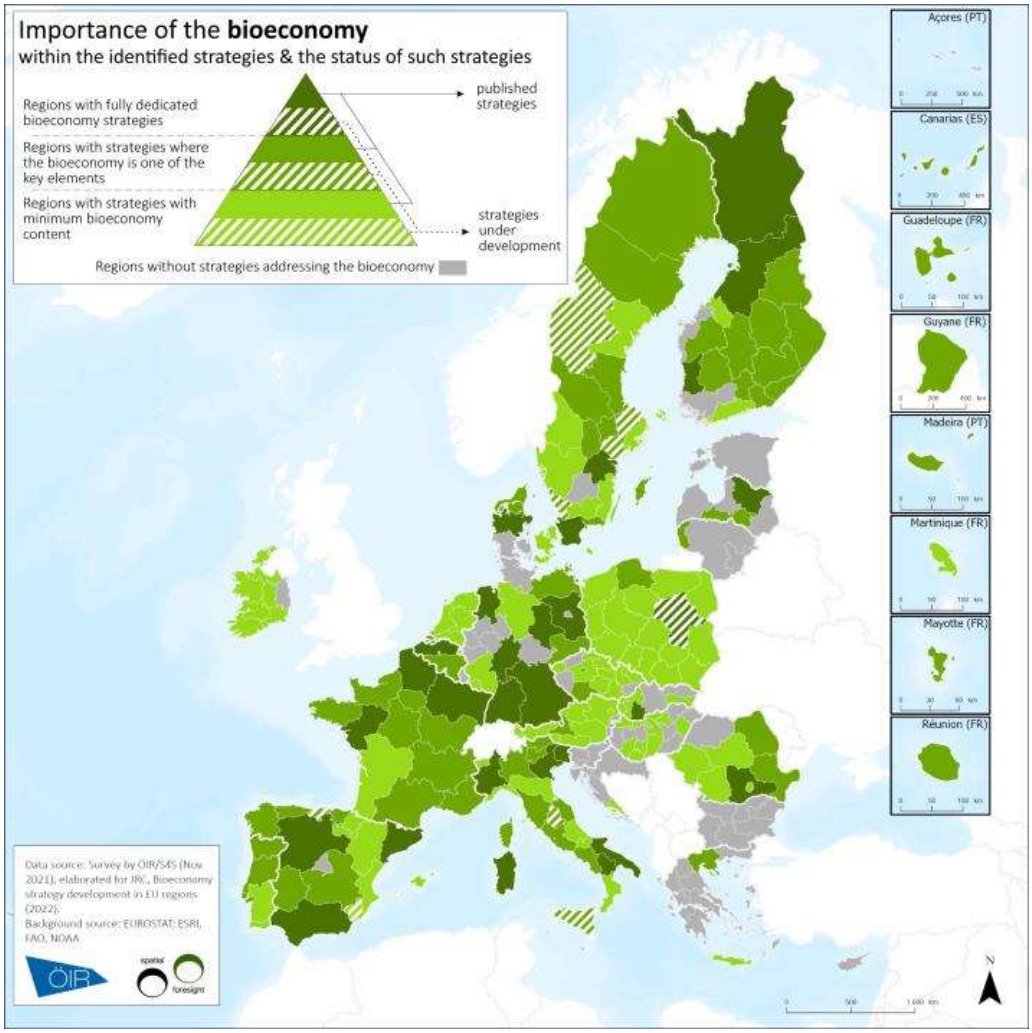

Figure 17. Distribution of regional bioeconomy strategies, EU, 2021. Source: (Haarich & Kirchmayr-Novak, 2022)

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Circular Economy Action Plan

The EU's revised Circular Economy Action Plan[14] is a strategic set of initiatives devised to transition the EU towards a more sustainable and circular economic model. Launched in 2020, the plan sets forth a multifaceted approach aimed at decoupling economic growth from resource consumption and environmental degradation. Its overarching goals encompass the promotion of sustainable production and consumption patterns, the reduction of waste generation, and the maximization of resource efficiency. The plan operates within a broad spectrum of policy areas, with a particular focus on product design, waste prevention, recycling, and the integration of circularity principles into various sectors of the economy, such as manufacturing, construction, and textiles. It also emphasizes the importance of fostering innovation, eco-design, and extended producer responsibility, while simultaneously engaging stakeholders and promoting the concept of a circular economy at both national and international levels, thereby contributing to the EU's broader sustainability and climate objectives.

REPowerEu Plan

The REPowerEU Plan[15] is a comprehensive strategy launched by the EC in response to the energy supply crisis resulting from Russia's 2022 invasion of Ukraine. It aims to rapidly reduce the EU's dependency on Russian fossil fuel imports by diversifying energy supplies, improving energy efficiency, and accelerating the transition to renewable energy sources. The plan suggests leveraging financial instruments and funds to support investments in energy transitions, infrastructure, and technological innovation. Furthermore, it emphasises the need to increase resilience against future energy supply disruptions, thereby enhancing the EU's energy security while also supporting its climate goals and the transition to a clean energy economy. Key objectives outlined in the plan include the following points.

- Diversification of Gas Supplies: Efforts to secure alternative sources of natural gas, including increasing imports of compressed natural gas (CNG), liquefied natural gas (LNG) and pipeline gas from non-Russian suppliers.
- Acceleration of Renewable Energy Deployment: Encouraging faster roll-out of renewable energy projects to reduce the demand for fossil fuels and decrease GHG emissions.
- Energy Efficiency Enhancement: Promoting energy-saving measures across industries, buildings, and households and increasing the binding RED energy efficiency target from 9% to 13%.
- Energy Infrastructure Improvement: Investing in critical energy infrastructure, including gas interconnectors, electricity grids, and hydrogen networks, to facilitate the integration of renewable energy and ensure secure energy supplies across member states.

[14] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
[15] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

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Biomethane Action Plan

As a part of the REPower EU Plan, the Biomethane Action Plan[16] focuses on increasing the production and use of biomethane as a renewable energy source to support the transition towards a more sustainable and circular economy. The production potential of biomethane in the EU is supported by a growing demand and the establishment of national policy frameworks aiming at the decarbonization of the transport sector and the integration into the natural gas grid. This approach aligns with the EU's renewable energy targets, GHG emissions reduction goals, and the ambition to enhance energy security and sustainability. Key actions outlined in the EU's biomethane strategy include:

i) setting mandatory renewable fuel targets for member states to boost the use of renewable energy in the transport sector, thereby reducing carbon dioxide emissions and increasing supply security; the most prominent goal is to reach 35 billion m^3 (350 TWh) in biomethane production by 2030;
ii) establishing the Biomethane Industrial Partnership (2022) to promote active engagement between the EC, EU countries, industry representatives, feedstock producers, academics, and NGOs;
iii) supporting EU member states in their development of national strategies on biomethane production;
iv) incentivising the upgrading of biogas into biomethane;
v) encouraging the use of advanced feedstocks, such as algae, and the integration of innovative technologies for biomethane production to meet sustainability criteria;
vi) supporting the commercialisation and scalability of biomethane projects, emphasizing the role of small-scale plants and the importance of subsidies for achieving economic viability;
vii) emphasising the development of biomethane for transportation, including bio-CNG and bio-LNG, to leverage biomethane's potential in reducing GHG emissions in the transport sector;
viii) assessing infrastructure challenges and bottlenecks hindering the cost-efficient deployment of biomethane.

Solar Energy Strategy

Also contained within of the REPowerEU Plan, the EU's Solar Energy Strategy[17] focuses on accelerating the deployment of solar energy across the EU to reduce GHG emissions, enhance energy security, and drive economic growth through green technology innovations. It is considered a critical component of the EU's comprehensive approach to achieving its climate goals, enhancing energy security, and fostering sustainable economic growth. Key components of the strategy include the following points.

[16] https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en
[17] https://energy.ec.europa.eu/topics/renewable-energy/solar-energy_en

- Rapid Expansion of Solar PV Capacity: Increase cumulative PV capacity in the EU to over 320 GW of solar PV by 2025 and almost 600 GW by 2030, thereby contributing to reducing GHG emissions by at least 55% by 2030 compared to 1990 levels. According to Jäger-Waldau et al. (2020), this expansion will require a compound annual growth rate of between 12 and 15% from 2020 to 2030, which will expand the annual PV market from ca. 16.5 GW in 2019 to 50-80 GW by 2030. Such an expansion would revive the European solar manufacturing industry and create over 100,000 jobs along the value chain.
- Solar Energy Integration into All Sectors: Integrate solar energy into residential, commercial, and industrial sectors to increase energy efficiency and reduce reliance on fossil fuels.
- Support Innovation and Technology Development: Invest in research and innovation to reduce solar technology costs, improve energy efficiency, and integrate technologies into energy systems. Prominent initiatives include the development of new solar panel technologies, energy storage solutions, and smart grid technologies.
- Regulatory and Financial Support: Encourage the adoption of solar energy through measures like streamlining permitting processes, providing subsidies and grants, and facilitating access to financing for solar projects.
- Energy Independence: Develop domestic renewable energy sources to alleviate security concerns resulting from dependency on external energy suppliers.

National Energy and Climate Plans

The EU's National Energy and Climate Plans[18] (NECPs) are a central component of the EU Energy Union and Climate and Energy Framework, aiming to ensure the EU meets its 2030 and 2050 climate and energy targets. The plans, required by the Regulation on the Governance of the Energy Union and Climate Action, are created by each EU member state and outline how they intend to achieve both their national and the EU's collective targets for GHG emission reductions, renewable energy uptake, energy efficiency improvements, and energy security. In practice, the NECPs reflect varying national circumstances, priorities, and capacities to contribute to the EU's collective energy and climate goals, which is supported in the flexible NECP common framework that accommodates for different national pathways towards a sustainable and secure energy future in the EU (Paoli & Geoffron, 2019). Key aspects of the NECPs include the following points.

[18] https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en

- Targets and Contributions: Outline of the intended contributions to the EU-wide targets of reducing GHG emissions by at least 40% by 2030 compared to 1990 levels, increasing the share of renewable energy to at least 32%, and improving energy efficiency by at least 32.5% by 2030.
- Policies and Measures: Policies and measures that member states will implement to achieve energy and climate targets, such as renewable energy investments, energy efficiency programs, and strategies for reducing emissions in key sectors like transportation, buildings, and industry.
- Integrated Approach: Emphasis on the interconnections between emissions reduction, energy efficiency, energy security, and the internal energy market to ensure a coordinated and efficient transition to a low-carbon economy.
- Public Participation: Engagement with stakeholders and the public in the development and implementation of NECPs.
- Progress Monitoring: Provisions for monitoring and reporting progress towards achieving the targets and implementing the outlined policies and measures. This ensures accountability and allows for adjustments to strategies as needed.
- Regional Cooperation: Emphasis on the importance of regional cooperation among member states to achieve energy security, market integration, and the coordinated deployment of renewable energy resources.

In 2023, EU member states were required to submit their updated NECPs in line with Article 14 of the Regulation on the Governance of the Energy Union and Climate Action. Thereafter, the EC published both its technical assessment of the NECP progress reports (European Commission, 2023a) and EU-wide assessment of the updated NECPs (European Commission, 2023d).

5.2 Regulations and Directives

European Climate Law

The European Climate Law[19] (REGULATION (EU) 2021/1119)[20] legally establishes the binding EGD goals of achieving climate-neutral economy and society by 2050 and negative emission levels thereafter. Furthermore, the law also sets the intermediate binding target of reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels. Key features of the legislation include:

[19] https://climate.ec.europa.eu/eu-action/european-climate-law_en
[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

i) the establishment of an independent European Scientific Advisory Board on Climate Change, which is tasked with reviewing climate data and identifying actions and opportunities to meet EU targets;
ii) the requirement of EU member states to establish a climate advisory body and submit a 30-year climate strategy;
iii) EC monitoring of legislative proposals aimed at meeting climate objectives;
iv) limiting the contribution of net removals to a maximum of 225 Mt of CO_2e to ensure sufficient mitigation efforts are made leading up to 2030 (With the aim of enhancing the EU's carbon sink in line with the 2050 climate-neutrality objective, the regulation also provides for the EU to aim for a higher volume of its net carbon sink in 2030);
v) allowing for the EC to propose a climate target for 2040 within 6 months of the first global stocktake under the Paris Agreement (The proposal is to be accompanied by a report containing the projected indicative EU GHG budget for 2030-2050);
vi) requiring the EC to report to the European Parliament and Council, within 6 months of each global stocktake under the Paris Agreement, on the progress the EU and member states are making towards meeting the objectives of the regulation.

Common Agriculture Policy Regulations

The legal framework of financing the CAP 2023-2027 is enacted by the Regulation on the Rules and Financial Support for CAP Strategic Plans[21] (REGULATION (EU) 2021/2115)[22] and the Regulation on Financing, Management and Monitoring of the Common Agricultural Policy[23] (REGULATION (EU) 2021/2116)[24], which outline how 40% of the CAP budget must be climate-relevant and demonstrate support for the general commitment to dedicate 10% of the EU budget to biodiversity objectives by the end of the EU's 2021-2027 MFF. The planned financial allocation designated in the regulations equals €387 for the CAP 2021-2027 period - €291.1 billion for the EAGF (€189 billion of which is designated for direct payments) and €95.5 billion for the EAFRD (€66 billion of which is designated for rural development) (European Commission, 2023c).

[21] https://eur-lex.europa.eu/EN/legal-content/summary/rules-and-financial-support-for-cap-strategic-plans.html?fromSummary=03
[22] https://eur-lex.europa.eu/eli/reg/2021/2115/oj
[23] https://eur-lex.europa.eu/EN/legal-content/summary/agriculture-in-the-eu-financing-managing-and-monitoring-rules.html?fromSummary=03
[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R2116

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Renewable Energy Directive

The EU Renewable Energy Directive[25] (RED) (DIRECTIVE 2009/28/EC)[26] is the key binding legislation for promoting the production and consumption of energy from renewable sources. Key aspects of the directive include setting binding renewable energy targets for EU members and energy sectors, mandating grid access prioritisation for renewables, and defining tools for the promotion of renewable energy, such as sustainability criteria for bioenergy fuel sources, a GoO system for renewably generated electricity, and international cooperation mechanisms. The binding measures within the directive have been updated twice; once in 2018, a.k.a. RED II, and once in 2023, a.k.a. RED III. Prominent updated energy targets of RED III (DIRECTIVE (EU) 2023/2413)[27] include the binding target of 42.5% renewable energy consumption in the EU by 2030, an increase from 32% set in 2018, and the solar energy target of at least 710 GW by 2030, meaning the EU must increase PV deployment to ca. 80 GW per year, a significant increase from the 40 GW installed in 2022 (PVCase, 2023).

In regard to biomass, the mandates defined in RED II outline how biomass used for energy must be produced, processed, and used in a sustainable and efficient way in order to optimise GHG savings and maintain ecosystem services. Specifically, the revised directive outlines the following points related to agricultural biomass used for energy purposes.

- The use of agricultural waste and residues must provide evidence of the protection of soil quality and soil carbon, Agriculture biomass must provide evidence that the raw material is not sourced from highly biodiverse forests.
- New biofuel plants must produce at least 65% fewer direct GHG emissions than fossil fuel alternatives. New biomass-based heat and power plants must produce at least 70% (80% in 2026) fewer GHG emissions than fossil fuel alternatives.
- Large-scale bioelectricity plants, i.e., above 50 MW, must either apply highly efficient cogeneration technology, apply best available techniques (BAT), achieve 36% efficiency (for plants above 100 MW), or use carbon capture and storage technology.

The RED III also promotes the gradual shift away from conventional biofuels to advanced biofuels (mainly produced from non-recyclable waste and residues) and other alternative renewable fuels (e-fuels) (European Commission, 2023b).

[25] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
[26] https://eur-lex.europa.eu/eli/dir/2009/28/oj
[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105

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Energy Taxation Directive

In 2003, the Energy Taxation Directive[28] (ETD) (DIRECTIVE 2003/96/EC)[29] created a common framework for harmonizing energy taxation policies among EU member states. It sets minimum tax rates for various energy products, including fossil fuels and electricity, while also providing flexibility for member states to offer tax incentives for renewable energy sources such as biofuels, biogas, and electricity generated from renewables like wind, solar, hydro, and biomass. By internalizing environmental costs and incentivizing cleaner energy options through reduced tax rates or exemptions, the ETD promotes the development and consumption of renewable energy within the EU. Furthermore, the directive not only fosters a transition towards more sustainable energy sources but also ensures fair competition among energy producers, thereby contributing to the EU's broader goals of reducing GHG emissions, enhancing energy security, and promoting economic growth through renewable energy investments.

Notably, in order to update the policy in accordance with the EU's commitment of at least 55% reduction in GHG emissions by 2030, a new revision of the directive, as part of the Fit for 55 package, was introduced in 2021[30]. Accordingly, a new structure of tax rates was established, referring to the energy content and environmental performance of fuels and electricity rather than to volume. Furthermore, the taxable base was broadened by considering more products and removing some of the current tax exemptions and reductions. Nevertheless, certain reductions remain (e.g., for electricity or advanced energy products produced from renewables. As a result, the new categorisation will tax the most polluting fuels at the highest level and removed national exemptions will result in lower margins for member states, which will make electricity and heat from fossil fuels more expensive and thus renewable energy sources like PV and biomethane indirectly more competitive (European Commission, 2021b; Lorin et al., 2023).

European Union Emissions Trading System

The EU Emissions Trading System[31] (EU ETS) (DIRECTIVE 2003/87/EC)[32] was launched in 2005 to make producers of GHG emissions pay for their emissions. Since then, it has undergone several revisions[33] and helped to reduce emissions from power and industry by 37%. The main aim of the system is to tackle climate change by reducing emissions and to finance the green transition of the EU. In 2024, it will also cover the maritime transport sector.

The system sets a limit for emissions of installations in the energy sector and manufacturing industry as well as aircraft operators. These entities cause around 40% of the EU's emissions. The limit or 'cap' includes emission allowances, which are reduced every year in line with the EU's climate target to become climate neutral by 2050. Companies receive some allowances for no cost but must primarily buy

28 https://energy.ec.europa.eu/topics/markets-and-consumers/energy-taxation_en
29 https://eur-lex.europa.eu/eli/dir/2003/96/2023-01-10
30 https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3662
31 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en
32 https://eur-lex.europa.eu/eli/dir/2003/87/2023-06-05
33 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en

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allowances on the EU carbon market or from other companies to fully account for their emissions. The revenues from the EU ETS are invested in renewable energy, energy efficiency improvements, and low-carbon technologies.

As part of the Fit for 55 package, the latest revision in 2023 planned the creation of a second trading system named ETS 2[34]. This system covers CO_2 emissions upstream from fuel combustion in buildings, road transport, and other sectors mainly in small industry. The ETS 2 will come into effect in 2027 (see also Effort Sharing Regulation subsection).

Regulation on the Governance of the Energy Union and Climate Action

The Energy Union Strategy of 2015 founded the EU Energy Union[35], aimed at ensuring affordable, secure, and clean energy supplies for consumers in the EU. The 2018 Regulation on the Governance of the Energy Union and Climate Action[36] (REGULATION (EU) 2018/1999)[37], as part of the Clean energy for all Europeans package[38], established the common rules for the planning, reporting, and monitoring within the EU Energy Union. It focuses on meeting the EU's 2030 energy and climate targets and how EU countries and the EC can achieve it together. The governance is based on EU and national strategies, reporting, monitoring and data publication as well as NECPs in the EU countries. The strategy of each member state requires the consultation of citizens, businesses and regional authorities in the creation process, as well as several assessments rounds of the EC. Each country has to submit a progress report every 2 years in order to monitor the EU's progress towards achieving the targets.

EU Renewable Energy Financing Mechanism

The Regulation (EU) 2020/1294[39] manages the functioning of the EU's renewable energy financing mechanism[40], which operates within the governance of the EU Energy Union. The renewable energy financing mechanism was established in 2021 to support renewable energy projects and contribute to renewable energy deployment in accordance with the EU RED. The funding comes from voluntary payments of EU member state governments, EU programmes, and the private sector, with the option to indicate a preferred project. The funding supports regions to finance projects in order to meet renewable

[34] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/ets-2-buildings-road-transport-and-additional-sectors_en
[35] https://energy.ec.europa.eu/topics/energy-strategy/energy-union_en#:~:text=The%20energy%20union%20strategy%20(COM,sustainable%2C%20competitive%20and%20affordable%20energy.
[36] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/governance-energy-union-and-climate-action_en
[37] https://eur-lex.europa.eu/eli/reg/2018/1999/oj
[38] https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
[39] https://eur-lex.europa.eu/eli/reg_impl/2020/1294/oj
[40] https://energy.ec.europa.eu/topics/renewable-energy/financing/eu-renewable-energy-financing-mechanism_en

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energy targets if their local economy is under pressure. Additionally, joint projects are supported to foster cooperation between the member states.

Alternative Fuels Infrastructure Regulation

As part of the Fit for 55 package effort to update the 2014 Directive on the Deployment of Alternative Fuels Infrastructure[41] (DIRECTIVE 2014/94/EU)[42], the 2023 Alternative Fuels Infrastructure Regulation[43] (AFIR) aims to further minimise dependence on oil and to reduce the environmental impact of transport by further developing the alternative fuels infrastructure. According to the definition in the regulation alternative fuels have an enhanced environmental performance and contribute to the decarbonisation of transport (e.g., hydrogen, electricity, biofuels, synthetic and paraffinic fuels, natural gas including biomethane (CNG, LNG), and liquefied petroleum gas (LPG)). The regulation defines minimum mandatory infrastructural requirements for road vehicles, vessels, and stationary aircraft (e.g., recharging points for natural gas, hydrogen, and electrical cars), as well as technical specifications for the infrastructure and user information requirements. These requirements must be transferred into EU member states' individual NPFs.

Effort Sharing Regulation

The Effort Sharing Regulation[44] (ESR) (REGULATION (EU) 2018/842[45]) was adopted in 2018 and focuses on emission reductions from road transport, heating of buildings, agriculture, small industrial installations, and waste management. These sectors are responsible for ca. 60% of EU GHG emissions but are not included in the EU ETS. The ESR is implemented to reach the EU's emission reduction target by 2030 and to set annual emission limits. As part of the Fit for 55 package, the regulation was last amended in 2023 (REGULATION (EU) 2023/857)[46] with new national targets to reduce emissions of ESR sectors by 40% compared to 2005. The responsibilities to achieve that target are distributed between the member states so that countries with higher GDP per capita have to achieve more ambitious reduction targets for reasons of fairness. Additionally, two non-EU member states, Iceland and Norway committed to the ESR. One instrument to achieve the emission reduction goals for 2030 is the separate emission trading system EU ETS 2 for buildings and transport (see also EU Emissions Trading System subsection).

41 https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en
42 https://eur-lex.europa.eu/eli/dir/2014/94/oj
43 https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/alternative-fuels-infrastructure-council-adopts-new-law-for-more-recharging-and-refuelling-stations-across-europe/
44 https://climate.ec.europa.eu/eu-action/effort-sharing-member-states-emission-targets/effort-sharing-2021-2030-targets-and-flexibilities_en
45 https://eur-lex.europa.eu/eli/reg/2018/842/oj
46 https://eur-lex.europa.eu/eli/reg/2023/857/oj

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Energy Efficiency Directive

The Energy Efficiency Directive[47] introduces rules and obligations to achieve the EU's energy efficiency targets. It contributes to the EU's climate goals by reducing the total energy consumption and aims to enhance present and future energy security and affordability. As part of the Fit for 55 package, the last revision of the directive[48] (DIRECTIVE (EU) 2023/1791)[49] was adapted in 2023 in order to implement the new 2030 target of reducing GHG emission by at least 55% and the energy consumption by 11.7% (compared to 2020). EU member states received two years to transpose the new elements into national law and have agreed to set their indicative national contribution based on measurable criteria reflecting national circumstances, i.e., energy intensity, GDP per capita, energy savings potential, and fixed energy consumption reduction. The revised directive established the 'energy efficiency first' principle in EU energy policies, which means that energy efficiency has to be considered in the preparation of important EU policies or investments.

Waste Framework Directive

Adopted in 2008, the Waste Framework Directive[50] (DIRECTIVE 2008/98/EC)[51] provides a legal framework for EU waste management practices with the overarching goal of protecting human health and the environment by promoting sustainable waste management strategies. The directive establishes principles and objectives for waste management, including waste prevention, recycling, and recovery, while also addressing the safe disposal of waste as a last resort. It emphasizes the concept of a 'waste hierarchy', which prioritizes waste prevention, followed by preparation for reuse, recycling, other recovery methods, and finally, disposal. Additionally, the directive outlines requirements for member states to establish waste management plans, monitor waste streams, and implement measures to prevent illegal dumping and hazardous waste practices. In regard to renewable energy sources, the directive mandates that EU countries will have to collect organic waste separately by 2024, offering an opportunity to scale-up the production of sustainable biogas and biomethane and create income opportunities for farmers and foresters.

47 https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en
48 https://energy.ec.europa.eu/news/new-energy-efficiency-directive-published-2023-09-20_en
49 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766
50 https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
51 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705

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6. NATIONAL LANDSCAPES IN VALUE4FARM DEMONSTRATION AND REPLICATION SITES

6.1 DENMARK

The Danish government's relaunch of The Danish Bioeconomy Panel, on October 4th, 2021, marked a significant stride towards sustainable socio-economic growth, environmental protection, and climate mitigation. This public-private partnership aims to develop and promote solutions, strengthening Denmark's position as a global leader in sustainable intensive food production and an innovative bioeconomy (Danish Bioeconomy Panel, 2022). This initiative builds on the work of a former Bioeconomy Panel creating recommendations for future protein supply (Danish Bioeconomy Panel, 2018, 2019), which has sparked a commercial development of green biorefineries in Denmark. Together with investments in state-of-the-art R&D on the green transition of agriculture and the energy sector, the panel accelerates the creation and implementation of ground-breaking solutions and necessary progressive regulation. The emphasis on responsible practices aligns with Denmark's commitment to various national and international climate and environmental obligations.

Denmark has committed to deliver ambitious reductions in GHG emissions by leveraging on existing and novel renewable energy solutions. The agricultural sector in Denmark is responsible for ca. 23% of national emissions, with production of cattle and pigs being the dominant source. The Danish government has pledged to reduce national emissions by 70% in 2030 relative to 1990 levels, corresponding to a reduction from the current 51.3 Mt CO_2e in 2018 (Prag & Henriksen, 2020). The reduction within agriculture is supported by governmental initiatives on a range of technologies (e.g., pyrolysis of biomass into biochar, green biorefining of grasslands, and rewetting of organic soils) as agreed upon within the *Agreement on the green transition of Danish agriculture* (*Aftale om grøn omstilling af dansk landbrug*) (Danish Government, 2021).

6.1.1 National Agriculture and Renewable Energy Sectors

Agriculture

As of 2019, ca. 61% of the Danish land area is under agricultural management, 13% is occupied by forestry, 14% by cities, roads etc., while natural areas including lakes and streams cover 12% (Odgaard, M. V., Kristensen, T., & Dalgaard, T., 2021). In the Danish Integrated NECP from 2019, ambitious policies for a cross-sector transition are laid out with emphasis on renewable energies and a more bio-based economy through bioenergy (e.g., biogas and biofuels).

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Energy Mix

Currently energy production in Denmark is primarily driven by oil and biofuels, including wood, biological waste, and agricultural biomass (see Figure 18). Biomass for heating is currently promoted by the absence of energy and CO_2 taxes on heat from renewable sources. Within power production, wind has become a dominant source over the last decades with a smaller increase in PV production appearing in recent years (see Figure 19).

The national production and use of renewable energy resources have increased steadily over the latest decades (see Figure 20), with bio-based resources delivering the majority of growth. The fraction of renewable energy in the Danish energy system has increased from ca. 5% in 1990 to around 45% in 2022 (see Figure 21).

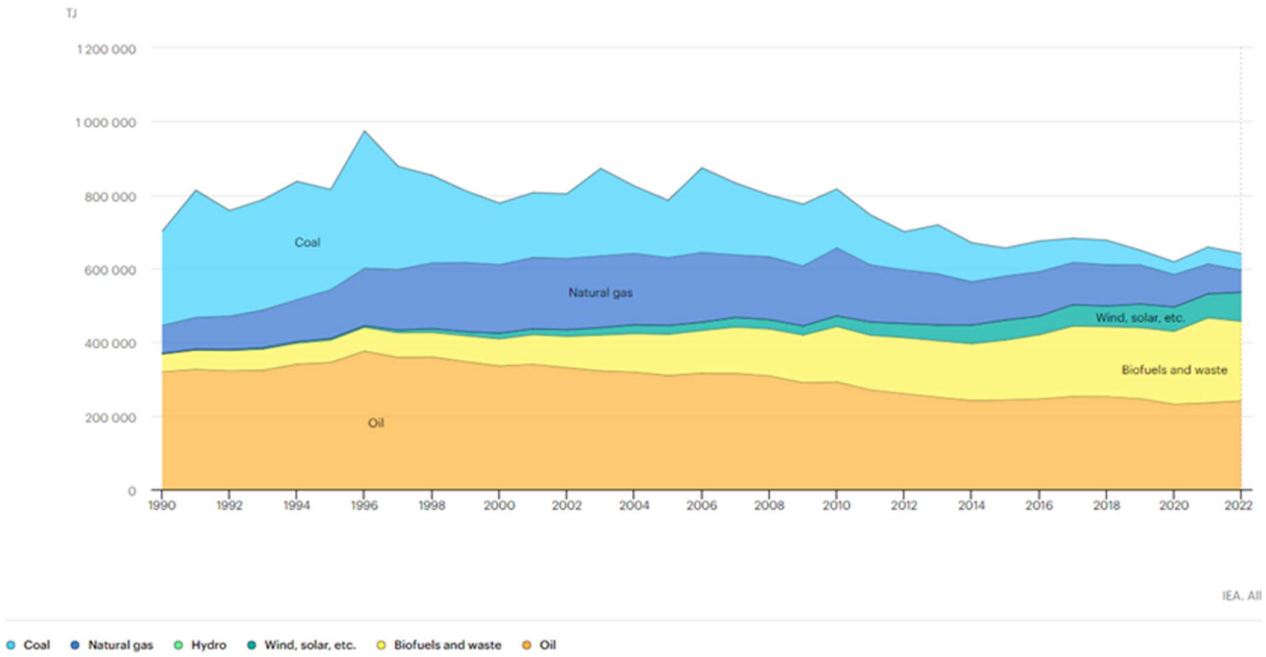

Figure 18. Total energy supply by source. Denmark, 1990-2022. Source: (IEA, 2023a)

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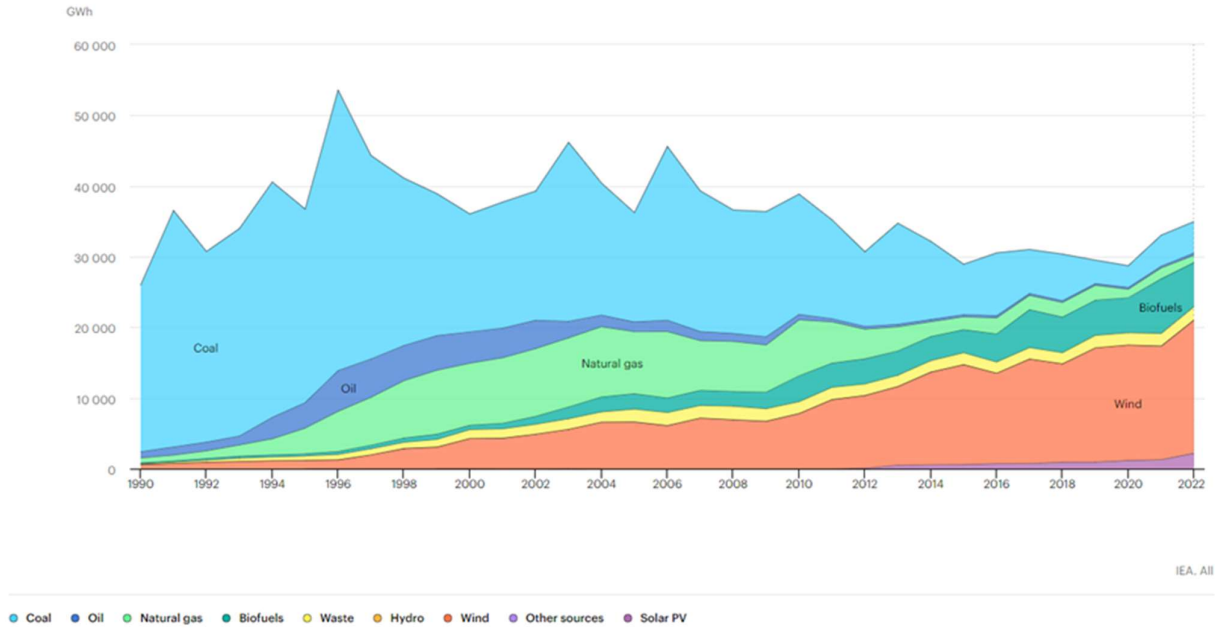

Figure 19. Electricity generation by source. Denmark, 1990-2022. Source: (IEA, 2023a)

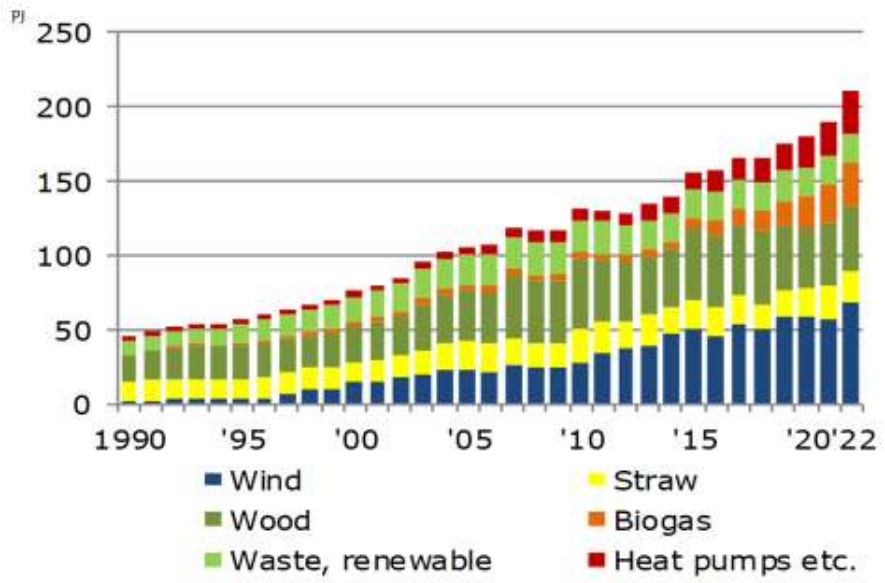

Figure 20. Production of renewable energy (PJ) by energy product. Denmark, 1990-2022. Source: (Danish Energy Agency, 2023a)

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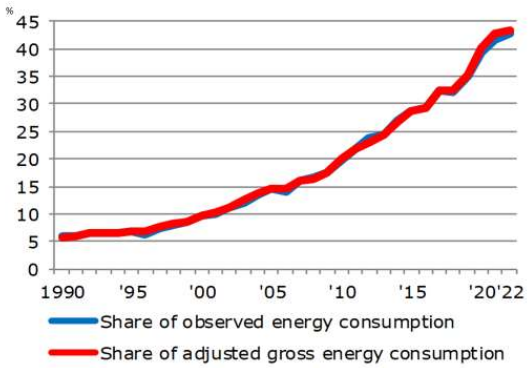

Figure 21. Renewable energy share (%) of total energy consumption. Denmark, 1990-2022. Source: (Danish Energy Agency, 2023a)

Energy Consumption in Agriculture

Total energy use in agriculture has dropped by 25% since 1990 (Danish Energy Agency, 2023a). The major fraction of current energy use is fossil fuel consumption with electricity as the second largest energy carrier in agriculture (see Figure 22). The decreased fossil energy consumption has led to decreased CO_2 emissions from agricultural energy use (see Figure 23), leaving a larger fraction to come from emissions from crop production (mainly N_2O) and from enteric fermentation in ruminants (CH_4).

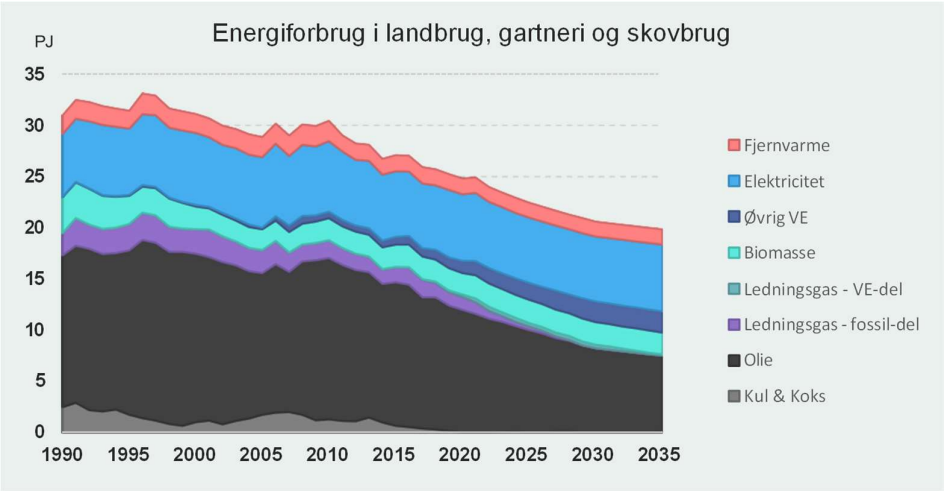

Figure 22. Energy use in farming, horticulture, and forestry from different resources (From top-down, the listed resources are district heating, electricity, renewable energy, solid biomass, gas - bio-based, gas fossil, oil, and coal). Denmark, 1990-2035. Source: (Danish Energy Agency, 2023b)

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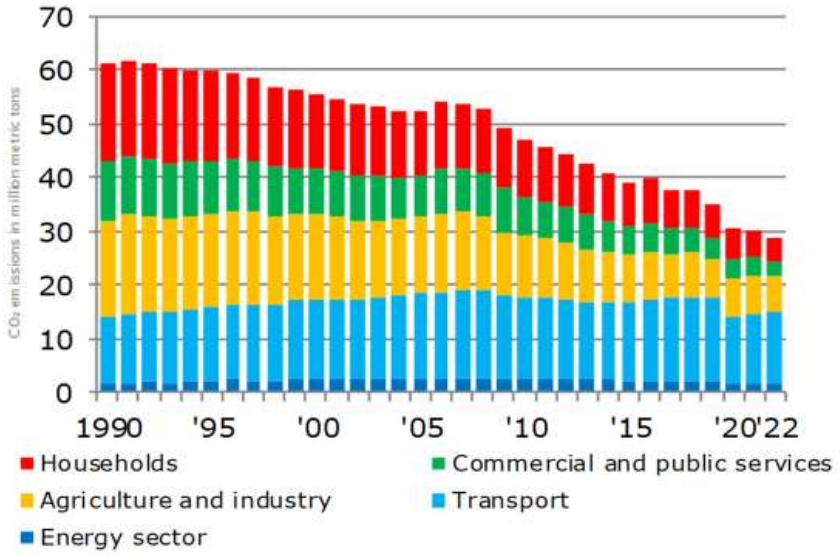

Figure 23. CO_2 emissions in end-use of energy in different sectors. Denmark, 1990-2022. Source: (Danish Energy Agency, 2023a)

6.1.2 Development of Agrivoltaics and Biogas/Biomethane

Agrivoltaics

The concept of agrivoltaics is novel in Danish policy frameworks covering agriculture, environment, and energy. This complexity makes planning frameworks and regulations regarding agrivoltaics close to non-existent. Yet, conventional PV systems, such as solar parks with fixed tilted panels, have in recent years received increased attention from farmers, landowners, renewable energy contractors and policy-makers due to their potential for climate change mitigation and additional income-generating assets. This has resulted in policies and regulatory frameworks for conventional PV systems including agrivoltaic systems, however without any specific distinction on agrivoltaic systems. Therefore, neither national nor regional planning and regulatory authorities in the areas of environment, agriculture, or energy affairs has established distinct categories for these multifunctional land-use systems.

Agrivoltaic pilot systems for research purposes have been established in recent years (e.g., at AU Viborg[52]and AU Flakkebjerg[53]).

[52] https://hyperfarm.eu/about/pilot-plants/pv-pilot-denmark/
[53] https://dca.au.dk/en/current-news/news/show/artikel/the-sun-shines-on-au-flakkebjerg

According to a 2023 JRC report, considering to use an average agrivoltaic system with a power density of 0.6 MW/ha, the area required in Denmark to reach the 2030 NECP PV capacity target of 7.84 GW, with only agrivoltaics, would be ca. 13,067 ha, which is 0.5% of the UAA, or 0.5% of arable land, or 6.7% of permanent grassland and meadow (Chatzipanagi et al., 2023).

Green Biorefineries and Local Alternative Protein Production

Significant R&D in green biorefineries was re-booted in Denmark around 2013. The renewed interest focused on how green biorefining could become a possible enabler for Danish agriculture to increase area with perennial crops, especially in nitrate sensitive areas, in order to solve the significant nutrient leaching and eutrophication problem in Danish agriculture, as well as produce alternative proteins to substitute soy import. Denmark is especially challenged regarding the EU Water Framework Directive[54], and after several extensions, the deadline for improving the Danish water environment is now 2027. Since 2013, the national funding body Green Development and Demonstration Program (GUDP) funded over 16 projects within R&D on Green Biorefining[55], including the scaling-up of the demonstration platform at AU Viborg[56] and two larger commercial green biorefineries[57,58] to help initiate the roll-out of the technology at commercial scale. In 2018 The Danish Bioeconomy Panel created thematic recommendations on 'Proteins for the Future' (Danish Bioeconomy Panel, 2018), including direct policy advise to enhance the support and the efforts to develop biorefineries for alternative protein production at scale and encouraged close collaboration "between universities, approved technological service providers, the business community, and other stakeholders in view of promoting the development of an innovative Danish biorefining industry". In Oct. 2021, the Danish parliament presented *The Agreement on a Green Transition of the Agricultural Sector*, where, among several other climate initiatives in agriculture, a large initiative on strengthening the plant-based food sector outlined how "260 million DKK (approx. €35 million) is allocated from 2022 to 2026 to a new support scheme for biorefining of grass in order to develop the production of new sources of plant-based protein for animal feed and human consumption." This support scheme has now been rolled out and the first applications for additional full-scale green biorefineries producing leaf protein concentrates from grasses and legumes will be funded and launched in 2024.

The two commercial facilities that were funded by GUDP in 2018, with 14 million DKK each, include a farm-scale biorefinery on the organic estate Ausumgaard[59] and a larger-scale biorefinery with the dedicated processing company BioRefine[60]. They have now been in operation since 2021, but the processing and business case of both still require improvements. The improved business case is believed

[54] https://environment.ec.europa.eu/topics/water/water-framework-directive_en
[55] https://gudp.lbst.dk/projekter/gudp-projekter/tema-sider/groen-bioraffinering
[56] https://bce.au.dk/forskning/forsknings-og-udviklingsomraader/industrial-biotechnology/research-groups/green-biorefining-technologies
[57] https://gudp.lbst.dk/projekter/gudp-projekter/tre-andelsselskaber-gaar-sammen-om-at-producere-klimaeffektivt-protein
[58] https://gudp.lbst.dk/projekter/gudp-projekter/vestjysk-gods-etablerer-landets-foerste-gaardanlaeg-til-groen-bioraffinering
[59] https://ausumgaard.dk/baeredygtig-energi/graesprotein/
[60] https://biorefine.dk/

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to be possible by increasing protein yields, and better value creation from the side streams of press cake fibre and a residual liquid known as brown juice.

The Danish biogas industry is regulated in order to reduce its inclusion of energy crops. This overall regulation has resulted in a big push towards green biorefineries since the press cake fibre coming from the green biorefinery does not count as an energy crop when it has undergone a wet fractionation for leaf protein concentrate production, allowing it to be added in none-regulated amounts to large scale biogas plants.

Biogas and Biomethane

Biogas technology has played a pivotal role in Denmark's energy supply system since the late 1970s, initially emerging in response to oil crises. Originating as small farm-based plants for heat production designed to primarily substitute fuel oil imports, the technology has evolved significantly. Today, Denmark boasts large farm biogas plants and centralised facilities with several hundreds of livestock farmers connected to a plant, providing district heating to local communities and contributing power to the grid. Furthermore, most newer biogas plants also produce upgraded biogas to the gas grid, which is distributed to households and industry sometimes over long distances. In 2020, Denmark had 64 decentralised farm biogas plants, 36 centralised biogas plants, and 51 wastewater treatment-connected plants, collectively producing 20 PJ of energy. Notably, two-thirds of the generated gas meets natural gas standards, with manure-based plants digesting ca. 16 Mt of animal manure annually, alongside various substrates, like household and industrial waste, contributing to the production of biogas (Lybæk & Kjær, 2021).

Traditionally, most biogas plants in Denmark have been concentrated in Jutland, where sandy soil and a high density of livestock provide favourable conditions. However, spurred by intensified climate policies and the directives outlined in the Danish Energy Agreement 2018[61], there is now a notable shift towards expanding biogas production in other regions, including Region Zealand, which encompasses most parts of Zealand, excluding the capital city of Copenhagen. The national targets set in the Energy Agreement 2018, influenced by various EU directives, include achieving 55% renewable energy in the overall energy supply by 2030, with specific targets for power and district heating. The plan also mandates that power consumption must be 100% renewable by 2030, with at least 90% of district heating coming from renewable sources. Furthermore, the Climate Agreement for Energy and Industry 2020[62] requires a substantial reduction of 70% in CO_2 emissions compared to the 1990 level, further influencing the trajectory of biogas development in Denmark (Danish Ministry for Climate, Energy and Utilities, 2020).

[61] https://investindk.com/insights/new-ambitious-danish-energy-agreement
[62] https://www.iea.org/policies/16838-climate-agreement-for-energy-and-industry-ccus

6.1.3 National Policies

Agrivoltaics

In Denmark, PV infrastructure, i.e., solar parks, is predominantly established on agricultural lands owned by farmers. According to Danish law on agricultural lands (Decree on the Use of Land Resources for Cultivation and Nature for 2024) and the law on direct payments (Decree on Basic Payment to Farmers for 2024) in the framework of the EU's Common Agricultural Policy (CAP), farmers in Denmark are eligible for agricultural subsidies for land areas with solar panels if they carry out agricultural activities on the land or maintain the land in an 'agricultural condition'. Sufficient agricultural activities, which must be done no later than October 25th each year, are defined as one of the following:

i) ploughing or cultivating the soil;
ii) growing crops eligible for subsidies;
iii) clearly mowing or keeping grazing pasture so that it can be monitored via satellite-based control;
iv) breeding and keeping farm animals on the land.

If no production takes place on the area, it must be maintained in an 'agricultural condition' so that the land is suitable for grazing or the cultivation of crops at any point in time. In practice, these conditions result in most PV facilities being established on agricultural lands holding the status 'permanent grass', allowing the landowner to receive agricultural subsidies in the form of direct payments since there is the production of grass under or between the solar panels, which is either grazed (typically by sheep) or mowed. The most important condition to receive agricultural support for land areas holding PV facilities are that the non-agricultural land-use does not significantly reduce the 'agricultural activity', so that agricultural activities cannot be carried out or is hampered by the non-agricultural activity during the cultivation period (March 15th to October 25th). Previously, landowners could apply for an extra agricultural subsidy on areas with solar panels based on the fulfilment of either the bio-scheme 'biodiversity & sustainability' or as part of the agricultural base condition 'GLM 8'[63], i.e., 4% of the total farm area is set aside for non-productive elements. However, a dialogue with the EC (February 14th, 2023), has clarified that there can no longer be solar panels on areas that are included in the fulfilment of these two schemes, since solar panels do not contribute to the specific objectives in the CAP regarding environment, climate, and biodiversity, and therefore the area under the solar panels cannot be used to fulfil GLM 8 nor be included in the bio-schemes. Nonetheless, it is still possible to apply for these bonus subsidies on areas between and around solar panels by dividing the areas under and between the panels into subsections and applying for these areas as independent fields (e.g., mowing fallow, flower fallow, pollinator fallow, etc.).

[63] https://lbst.dk/nyheder/nyhed/nyhed/pleje-af-graes-og-naturarealer-saadan-kan-du-opfylde-glm-8-i-2023

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Based on national land-use data from the Danish Energy Agency, areas with solar panels are included in the annual physical control population of applicants with non-monitorable subsidy conditions. This designation means that there is physical control of whether an agricultural activity takes place on the land area, contrary to the conventional use of satellite control of more common open-field agricultural lands.

Biogas and Biomethanation Support Schemes

Support schemes are in place to promote the upgrading of biogas to natural gas quality, instead of local use in combined heat and power (CHP) engines for the production of electricity and heat. As a consequence, most Danish biogas plants of a certain size are now equipped with gas upgrading to produce biomethane of grid quality, which peaked in 2023 with 39.6% of all gas in the natural gas grid being of biogenic origin (see Figure 24). This gas is today upgraded by gas scrubbing, where CO_2 and CH_4 are separated, producing concentrated streams of CO_2 and CH_4. Currently, part of the CO_2 from biogas plants is purified and used for industrial purposes. However, the conversion of CO_2 to biomethane has not yet been broadly implemented. Only one *ex situ* methanation plant has been deployed at demo-scale and one *in situ* methanation plant is being constructed. Upscaling of methanation technology is therefore only in its early years.

Figure 24. Fraction of biomethane in the natural gas grid. Denmark, 2020-2023. Source: (Energinet, 2023)

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In parallel with technical development and upscaling of methanation technology, there is a need for further legislative actions and policies aimed at supporting the upgrading of biogas. For *in situ* methanation, which will also be employed in the VALUE4FARM project, permits for H_2 injection into a biogas reactor are currently being evaluated by the Danish Environmental Agency in order to allow for the demo-scale demonstration of the technology as part of the AU-led project PowerLBG[64].

Many Danish biogas plants are potentially suited for the implementation of methanation when the economic framework is in place (Energy Maps, 2023). The economic basis for methanation, the production of e-methane from CO_2, and electricity-derived hydrogen is currently under development and is now part of a tendering process, where funds have been allocated through the Danish Energy Agency for the period of 2024-2030 (Energistyrelsen, 2023).

This tendering process is initiated to further the deployment of methanation technology for valorisation of CO_2 to increase the Danish production of renewable methane. In this case, methanation encompasses both biological and chemical methanation technologies.

The subsidy scheme presented in the tender includes a cap on the subsidies corresponding to 120 DKK/GJ (approx. €16/GJ). The amount subsidies are regulated in relation to actual gas prices will be reduced if gas market prices increase, thereby hindering the use of state subsidies to support extraordinarily high gas prices.

A major cost factor for methanation is estimated to be the renewable hydrogen needed for the reduction of CO_2 to methane. The cost of renewable hydrogen is comprised of both the costs of renewable electricity and subsequent electrolysis. Large scale deployment of electrolysis will support further industrialisation and cost reduction of renewable hydrogen, and thereby also the deployment of power-to-X technologies like methanation. As of 2024, a Danish electrolysis capacity of 5.46 MW is currently in operation with a large pool of plants in the pipeline (Brintbranchen, 2024).

6.2 Belgium

Bioeconomy is getting increasing attention in Belgium, with renewable energy integration as an important aspect. The country is divided into three regions (Wallonia, Flanders and Brussels), with different languages and governments. The following paragraphs provide an overview of the current status and future perspectives of renewable energy integration in Belgium. Since bioeconomy and renewable energy are regulated on a regional level, the focus of this chapter will mainly be dedicated to the VALUE4FARM technologies and value chains most relevant for Flanders, the region where the Belgian VALUE4FARM demonstration will take place.

64 https://missiongreenfuels.dk/powerlbg/

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6.2.1 National Agriculture and Renewable Energy Sectors

Agriculture

In Belgium, ca. 45% of total area is designated for agriculture. Since Belgium is a relatively small country, the actual land area used for agriculture is not as extensive as in larger countries. However, it is important to highlight that Belgium's agricultural sector is very efficient and innovative. Within the agricultural area, feed crops are accounting for more than half of used land, which shows the importance of animal husbandry in Belgium. Next to feed crops, arable farming (such as cereals and potatoes) and horticulture (e.g., vegetables and fruits) are an important sectors as well. (Landbouwleven, 2022; Vlaanderen, 2023c).

In 2022, agriculture accounted for ca. 0.7% of the Gross Domestic Product (GDP) in Belgium (O'Neill, 2023). In that year, Flanders exported agricultural products for €53.8 billion, i.e., 11.8% of the total export of Flanders, while it imported €46.4 billion, i.e., 9.4% of the total import in Flanders. Thus, the agricultural trade balance was €7.5 billion. This positive balance was mainly due to animal production (Vlaanderen, 2023a).

Energy Mix

When looking at the energy consumption in Belgium, it can be concluded that oil and gas are the most important part of the energy mix, which was 681 TWh in 2022 (see Figure 25). Of this energy mix, the share of renewables sharply increased over the last decade, with ca. 10.7% in 2022 (see Figure 26). Consequently, the carbon intensity of energy production is decreasing from 0.17 kg CO_2 per kWh in 2000 to 0.13 kg CO_2 per kWh in 2022 (Ritchie et al., 2022).

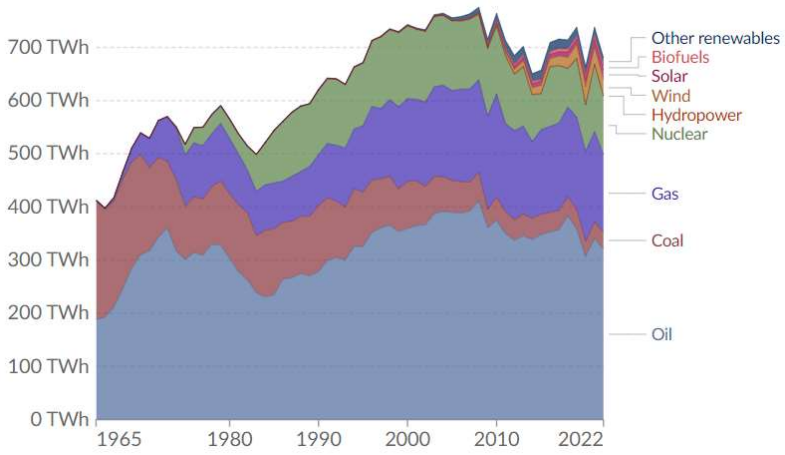

Figure 25. Energy consumption by source. Belgium, 1965-2022. Source: (Ritchie et al., 2022)

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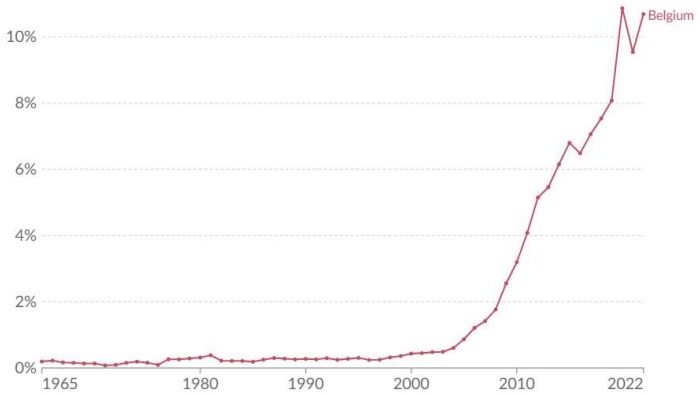

Figure 26. Share of primary energy from renewable sources. Belgium, 1965-2022. Source: (Ritchie et al., 2022)

When examining electricity production, which is one of the three main aspects of the energy mix, next to heating and transport, it can be seen that nuclear energy is the main source of electricity production in Belgium. In 2022, almost half of the country's total electricity generation was generated from nuclear sources (see Figure 27). Gas ranked second that year, making up 24.4% of Belgium's power mix (Statista Research Department, 2023). The share of renewable energy in the electricity production was 25.5% in 2022 (Ritchie et al., 2022). In 2022, the average annual price per MWh of electricity on the day-ahead market reached historic heights (€245/MWh) because of geopolitical conflicts, after reaching historical low prices in 2020 because of the COVID-19 crisis (Vanhecke, 2023).

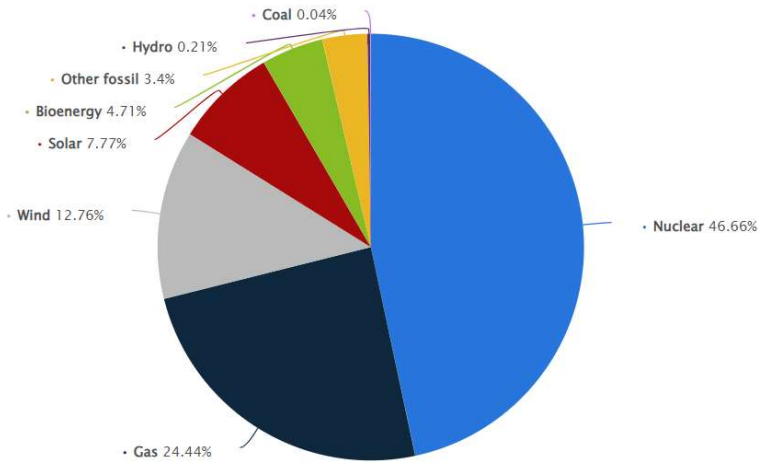

Figure 27. Electricity generation. Belgium, 2022. Source: (Statista Research Department, 2023)

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According to the IEA, 959 GWh of electricity was produced out of biogases in Belgium in 2021 (see Figure 28) (IEA, 2022a).

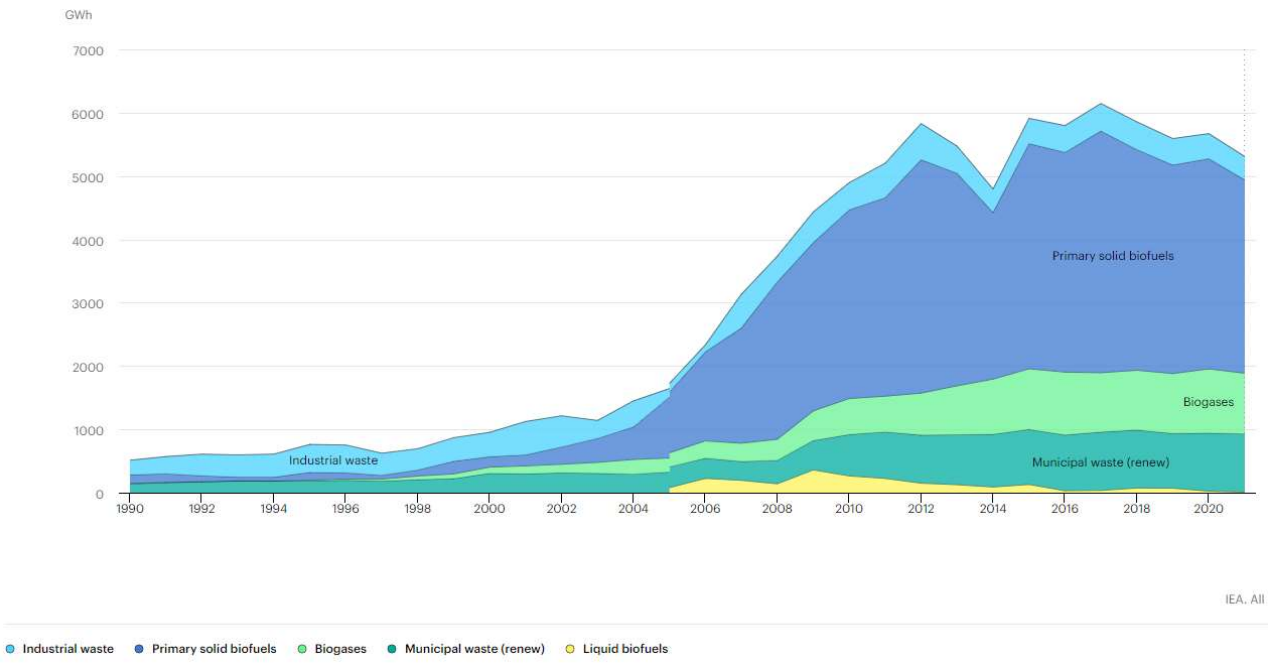

Figure 28. Electricity generation from biofuels and waste by source. Belgium, 1990-2021. Source: (IEA, 2022a)

Energy Consumption in Agriculture

In Flanders, the net primary energy consumption because of agriculture was 31,161 TJ, i.e., 8,665 GWh, in 2021, that of which natural gas is the most important energy carrier (accounting for ca. 81%). Energy produced out of biomass accounted for 7% of the total energy consumption. Since 2010, Flemish agriculture is a net producer of electricity, mainly because of CHP installations and solar energy. Compared to other sectors, agriculture is responsible for only a minor part of the Belgian energy consumption. Most of the country's energy consumption is related to industry (see Figure 29) (IEA, 2022a).

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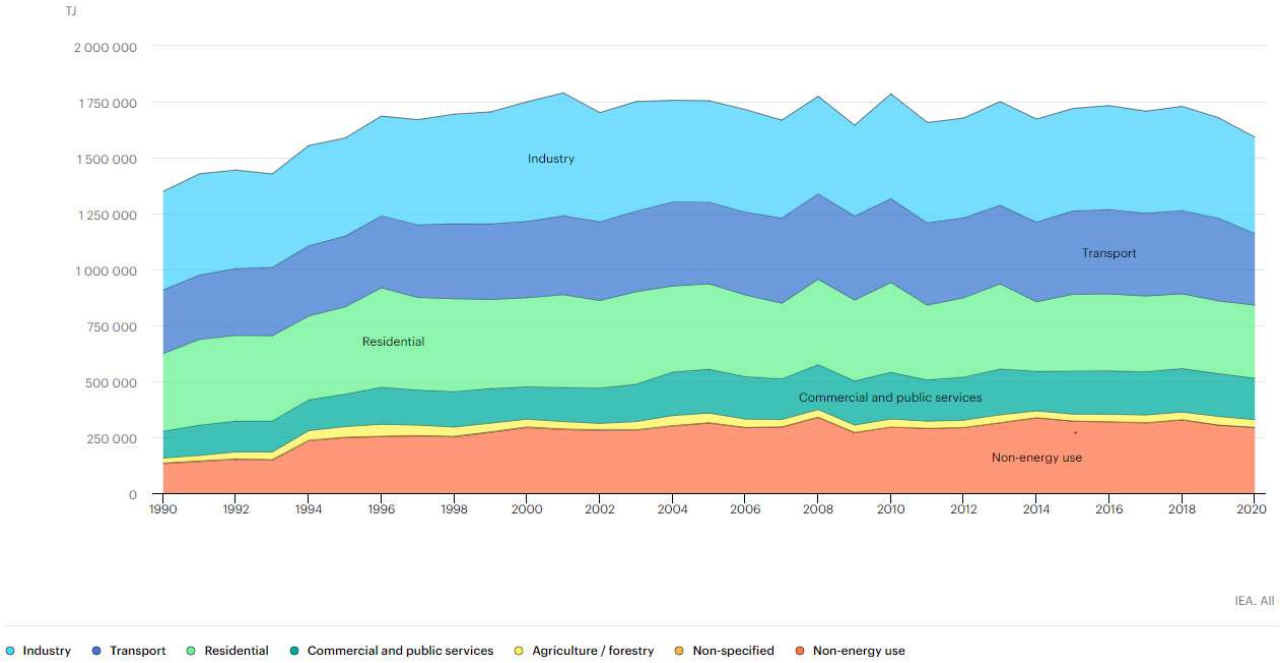

Figure 29. Total final energy consumption by sector. Belgium, 1990-2020. Source: (IEA, 2022a)

In 2021, the Flanders greenhouse vegetable sector was responsible for 51% of the energy consumption. Dairy farming and pig farming accounted for 8% and 7%, respectively. Arable farming accounted for 5% (see Figure 30).

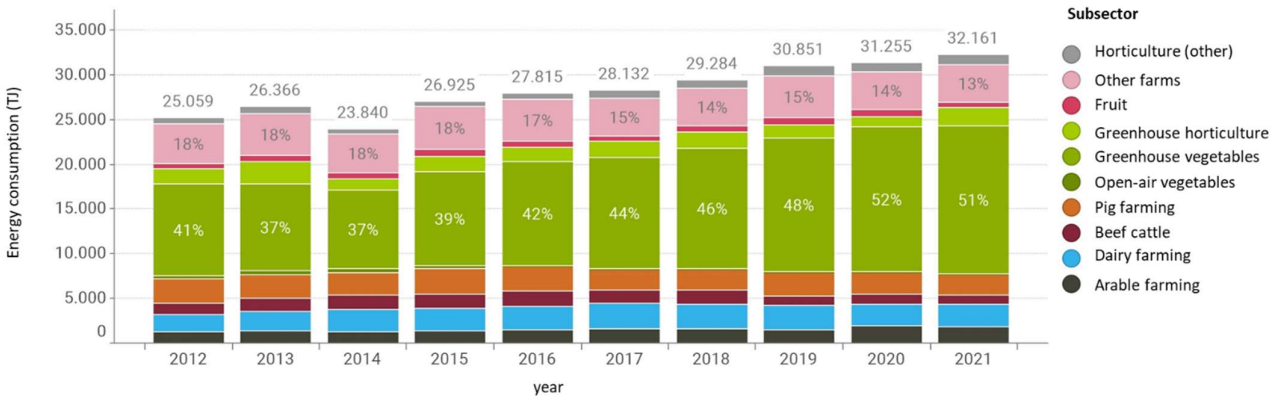

Figure 30. Energy per sub sector in agriculture. Flanders, 2012-2021. Derived from (Vlaanderen, 2023b)

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GHG emissions from Flemish agriculture were 7.8 Mt of CO_2e in 2022 (corresponding to 18% of the total Flemish ESR emissions), of which 31% is related to energy production and consumption (see Figure 31). Most of this energy is used for heating greenhouses and off-road mobility. Non-energetic emissions are responsible for 69% of the Flemish agricultural emissions and are mostly related to the digestion processes of ruminants and manure management (VEKA, 2023a).

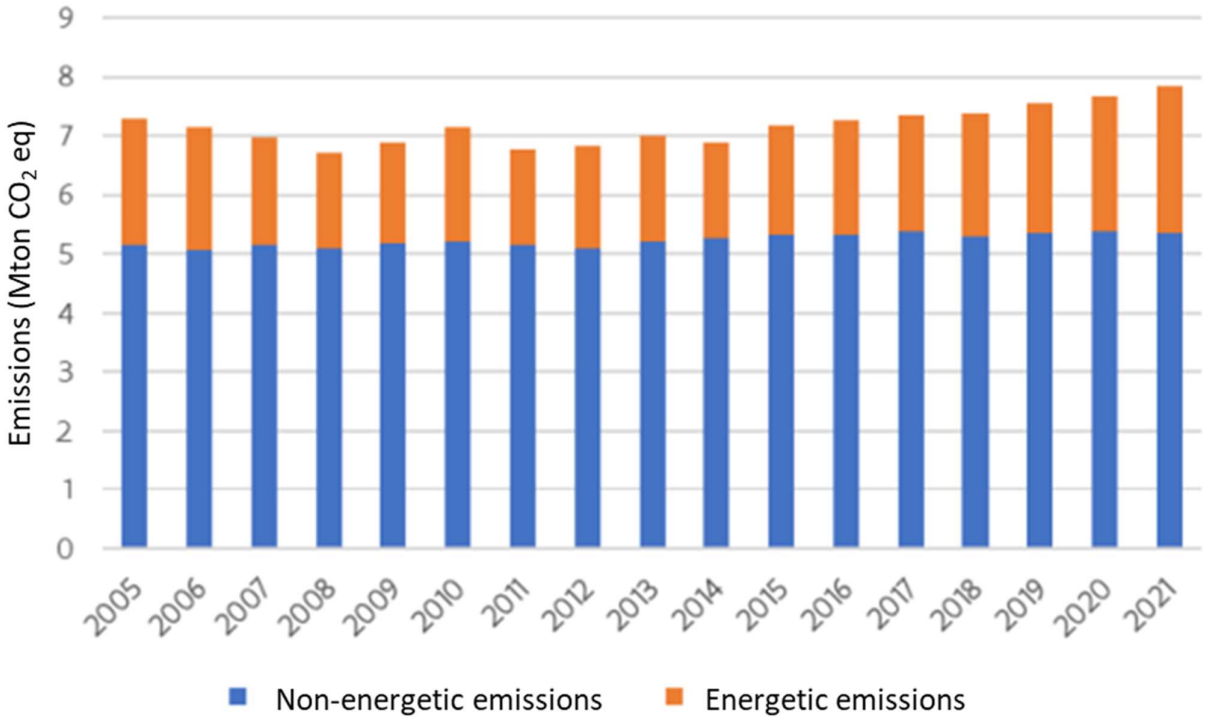

Figure 31. Evolution of GHG emissions in agriculture. Flanders, 2005-2021. Derived from (VEKA, 2023a)

6.2.2 Development of Agrivoltaics and Biogas/Biomethane

Agrivoltaics

Agricultural soils are quite expensive in Belgium, which is the main reason why agrivoltaics is not common. However, since almost half of the surface of Belgium consists of agricultural land, it could generate a wide

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range of possibilities. The potential is being investigated in research projects such as HyPErFarm[65], led by KU Leuven. There are also already some agrivoltaic pilot projects (e.g., TransFarm[66] and the fruit company Van der Velpen[67]), but it is not yet being used on large scale. Accordingly, there is no regulatory framework in place.

According to a 2023 JRC report, considering to use an average agrivoltaic system with a power density of 0.6 MW/ha, the area required in Belgium to reach the 2030 NECP PV capacity target of 22 GW, with only agrivoltaics, would be ca. 36,667 ha, which is 2.8% of the UAA, or 4.6% of arable land, or 7.5% of permanent grassland and meadow (Chatzipanagi et al., 2023).

Biogas and Biomethane Production

According to Biogas-E, the platform for anaerobic digestion in Flanders, there are 83 anaerobic digestion plants with a total installed capacity of 139 MWe, of which 34 are agro-industrial. Furthermore, there are 55 farm-scale anaerobic digestion plants with a total installed capacity of 1155 kWe. Accordingly, 748 GWh of green electricity and 868 GWh of green heat was produced in 2022. By the end of 2022, there were 3 active biomethane installations in Flanders, together producing 10 GWh of biomethane in 2022. Biogas upgrading is done via membrane filtration. Biomethane is being injected into the grid or used as transport fuel. There are no biomethane installations on farm-scale yet (Deraedt et al., 2023). Since the end of 2023, there is a fourth installation operational, aiming for 100 GWh biomethane per year (Biogas-E, 2023a). According to Valbiom, looking into non-food biomass valorisation in Wallonia, there are 55 active anaerobic digestions plants with a total installed capacity of 43.3 MWe, of which most are agro-industrial. Similar to the situation in Flanders, most of the valorisation is via a CHP. Hence, in 2021, there was a production of 231 GWh green electricity and 284 GWh green heat (Valbiom, 2022).

Both in Flanders and Wallonia, several other biogas and biomethane facilities are in the pipeline, so there is an expected growth for the coming years. To be compatible with the natural gas grid, biomethane needs to have a purity of 97.5% CH_4 (Fluvius, 2024). It is expected that Belgium has the ability to have a production of 6.3 TWh biomethane by 2030 if suitable measures are implemented, such as building new plants and retrofitting existing ones (Biogas-E, 2023c; European Commission, 2021a).

The support scheme depends on the region in Belgium. In Flanders, there is a limited investment support for biomethane production through anaerobic digestion upgrading or gasification. The support is limited by the size of the enterprise. While small enterprises can apply for 65% of investment support, large enterprises can apply for only 45%. The support is capped at €250,000 per project and there is no operational support to be added. In Wallonia, the investment support is lower, with a maximum of 27.5% funded. However, the operational support is much stronger. This support scheme is based on GoOs and a quota system for energy suppliers. The GoOs can only be received by plants based in Wallonia and injected into the gas grid. These GoOs can be sold to CHP plants in Wallonia at a current price of €75/MWh. For CHP plants who have bought GoOs, there is financial support as well (Jens et al., 2021).

[65] https://hyperfarm.eu/
[66] https://hyperfarm.eu/about/pilot-plants/pilot-plant-transfarm-kul/
[67] https://vilt.be/nl/nieuws/primeur-tegelijk-peren-en-energie-oogsten

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Digestate Use

Digestate can be used as a fertiliser on agricultural fields, fully closing the nutrient cycle. However, some important points of attention need to be further considered. Therefore, a handbook of good practices was created in 2021 by Vlaco, which will be integrated in the *Protocol of Good Practices for Handling Already Existing Residual Crop Streams and Usage of Digestate* (D2.5) (Vlaco, VCM, Biogas-E, Febiga, ILVO, Inagro, & Universiteit Gent, 2020).

6.2.3 National Policies

Belgium's energy and climate policy is divided between the federal government and the regional governments of Flanders, Wallonia, and the Brussels-Capital Region. The federal government is responsible for electricity transmission and large-scale generation, transport of natural gas and oil, nuclear energy, security of energy supply, price policy, consumer protection, the national rail system, transportation fuels, offshore energy, and energy research, development, and demonstration (RD&D) related to its competences. Regional governments are responsible for renewable energy (except offshore energy), energy efficiency and GHG emissions (except for federal buildings and vehicles), distribution of electricity and natural gas, regulation of retail energy markets, vehicle registration, public transportation, urban and rural planning, and energy RD&D related to their competences (IEA, 2022b).

Driven by renewable energy targets, Belgium wants a transition towards a low-carbon economy while ensuring security of supply, lowering costs for consumers, increasing market competition, and continuing integration with the European energy system. By 2025, most nuclear electricity generation will be phased out. However, it was decided recently to extend 2 GW of nuclear capacity by ten years. Since fossil fuel is still accounting for ca. 70% of Belgium's energy supply, more aggressive policies are needed to reduce the fossil fuel dependency and accelerate emission reductions, especially given that the nuclear phase-out will increase the carbon intensity of electricity generation.

National Energy and Climate Plan

In order to determine the future perspectives of the energy mix in Belgium, the country presented its NECP 2021-2030 in 2019. An updated draft of this NECP was presented to the EC in November 2023 and a finalized version is expected on June 30th, 2024 (Belgian Government, 2023). This plan is a ten-year integrated document mandated by the EU to each of its member states in order for the EU to meet its overall GHG emissions targets. The plan aims to define measures adapted to different dimensions. More specifically, the following targets have been defined (Belgian Government, 2019):

i) 35% GHG emission reduction in non-ETS sectors by 2030 relative to 2005 levels;
ii) reduction of GHG-ETS emissions by 35% compared to 2005;
iii) energy and climate neutral federal government buildings by 2040;

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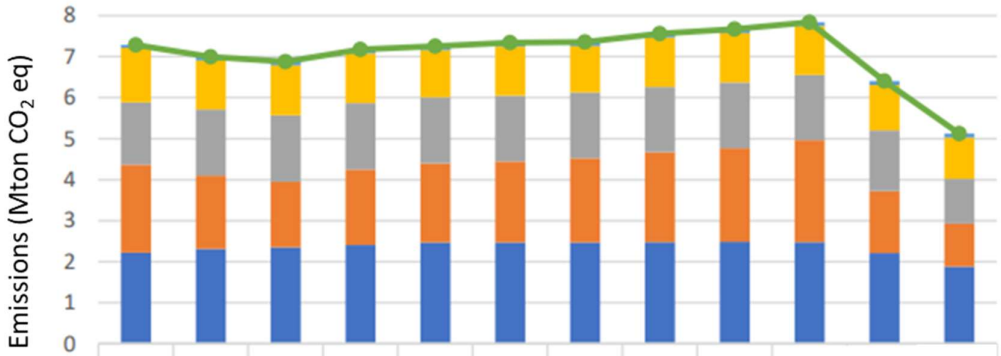
iv) 7% first generation biofuels in the mix between 2021-2030;
v) 10.5% biofuels reached in degree of admixture by 2030;
vi) 4GW installed offshore wind capacity by 2030;
vii) 33.1 Mtoe final energy consumption by 2030 (-12% compared to BAU);
viii) 39 Mtoe primary energy consumption by 2030 (-15% compared to BAU);
ix) 17.5% renewable energy consumption by 2030;
x) increase renewable energy sources by 18.3% of final gross energy consumption.

6.2.4 Regional Policies (Flanders)

Flanders updated its Flemish Energy and Climate Plan in May 2023, sharpening the GHG emission reduction targets in ESR sectors towards 40% by 2030 (compared to 2005 levels). Next to this, Flanders wants to achieve 91,845 TWh of energy savings and 31,974 GWh of renewable energy production in 2030 (VEKA, 2023b). More specifically for agriculture, this can be achieved by biogas production. In order to follow-up the progress, the Flemish Energy and Climate Agency will publish every October a follow-up report, analysing the evolution of GHG emissions in Flanders and providing the state of play of the measures mentioned in the plan. As can be concluded from Figure 32, energy-related GHG emissions should be decreased to 1.0 Mt of CO_2e in 2030, while in 2021 this still was 2,5 Mt CO_2e.



	2005	2013	2014	2015	2016	2017	2018	2019	2020	2021	2025	2030
Urea and lime use	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Soil	1,3	1,2	1,2	1,2	1,2	1,2	1,1	1,2	1,2	1,2	1,1	1,0
Manure storage	1,5	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,5	1,1
Energetic emissions	2,1	1,8	1,6	1,8	1,9	2,0	2,1	2,2	2,3	2,5	1,5	1,0
Digestion processes	2,2	2,3	2,4	2,4	2,5	2,5	2,5	2,5	2,5	2,5	2,2	1,9
Total	7,3	7,0	6,9	7,2	7,3	7,3	7,4	7,6	7,7	7,8	6,4	5,1

Figure 32. Evolution of the GHG emissions in Flemish agriculture and the 2025 and 2030 targets. Derived from (VEKA, 2023a)

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In order to achieve the defined goals within GHG emission reductions, the Flemish government approved specific indicators to be achieved by 2030 (VEKA, 2023a):

i) 582 – 726 farm-scale anaerobic digestion plants, which is a very relevant target for the Belgian VALUE4FARM demonstration;
ii) number of animals subject to emission reducing technologies, such as adapted stable system for swine, feed strategies for cattle, eco regulations, etc. (no indicative numbers have been provided, but this is considered as important points of attention);
iii) subsidies for energetic measures via the Flemish Agriculture Investment Fund *(Vlaams LandbouwInvesteringsFonds* - VLIF)[68]; in 2022, there were €47,204,419 VLIF subsidies accounting for 39,709 t CO_2 reduction per year (Energy efficiency measures and the promotion of renewable energy are the subject of research and awareness raising and can receive investment support).

In order to further finetune the Flemish Energy and Climate Plan, a public consultation round was established in January 2024, providing stakeholders with the opportunity to answer 39 questions related to transport and mobility, buildings, agriculture, industry, renewable energy and waste (VEKA, 2024).

Next to the Flemish Energy and Climate Plan, Flanders also published its Climate Strategy 2050[69]. In this vision document, it is stated that following the principles of Trias Energetica[70], energy emissions in the agricultural sector will be further reduced. First and foremost, general energy use in the sector will be further reduced thanks to energy savings and increased energy efficiency (e.g., energy-efficient infrastructure and machinery, reuse of residual heat, heat recovery, use of residual CO_2 in greenhouse horticulture, etc.). The remaining energy demand of the Flemish agricultural sector by 2050 will be completed to the maximum via the use of renewable energy from wind and solar energy, the use of biogas from (small-scale) anaerobic digestion plants, heat pumps, geothermal energy, biomass, etc., partnered with the provision of feasible energy storage systems. In greenhouse horticulture, which has a significant share of primary energy consumption within the agricultural sector, Flanders wants to promote the maximum use of green and residual heat (Vlaanderen, 2019).

Consequently, there are funding opportunities for Flemish organisations to develop and support renewable energy integration in agriculture. Some (non-imitative) examples are listed.

[68] https://www.vlaanderen.be/organisaties/administratieve-diensten-van-de-vlaamse-overheid/beleidsdomein-landbouw-en-visserij/agentschap-landbouw-en-zeevisserij/afdeling-ondernemen-en-ontwikkelen/vlaams-landbouwinvesteringsfonds
[69] https://www.vlaanderen.be/publicaties/vlaamse-klimaatstrategie-2050
[70] https://platformenergietransitiedelft.nl/trias-energetica/

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- VALUE4FARM (2023-2027, Horizon Europe)[71]: Inagro will demonstrate *in-situ* biomethanation on farm-scale and provide solutions to decarbonize agricultural transport.
- SEMPRE-BIO (2022-2026, Horizon Europe)[72]: Four Flemish partners are involved in this European project to produce BioLNG and liquid CO_2 from raw biogas at a dairy farm.
- RE-GREENHOUSE (2023-2027, Interreg NWE)[73]: This European project focuses on integrating renewable energy in greenhouses, which is very important in the Belgian agricultural context since a lot of energy is used for heating greenhouses.
- Biogas-Mambo (2020-2025, SBO)[74]: In this Flemish project, two different biogas upgrading technologies are being compared.
- Renewable Energy (2021-2023, PDPO)[75]: In this Flemish project, Inagro and HoWest are optimizing the integration of renewable energy in agriculture by performing measurements and calculations and providing a decision support tool.
- Enerpedia (2021-2025)[76]: This is a Flemish initiative in which Inagro and twelve partners are working on raising awareness on the importance of renewable energy in agriculture.

Biogas and Biomethane Support Schemes

The organization Biogas-E provides an overview of the support schemes for biogas and biomethane in Flanders. It consists of subsidies from the Flemish Energy and Climate Agency (VEKA) via certificates or investment subsidies. Furthermore, there is also a call for green heat. Next to this, there are also possible subsidies from the Department of Agriculture and Fisheries (via VLIF), subsidies from the Public Waste Agency of Flanders (OVAM), support from the Federal Public Service Finance, and support from the Flemish Agency for Innovation and Entrepreneurship (VLAIO) (Biogas-E, 2022).

However, due to lack of adequate support (both financial and political) combined with difficult and time-consuming permitting, projects are struggling to develop. Current biomethane capacity remains poor and only 30 GWh is produced annually. Consequently, today significant amounts of Flemish feedstocks (mainly manure) are exported for biomethanisation in neighbouring countries (Regatrace, 2022).

Similarly, Wallonia published its *Plan wallon Energie Climat*, describing the targets Wallonia sets regarding climate and energy and the measures it takes to achieve these targets (Awac, 2024). An overview of the support measures for biogas and biomethane facilities in Wallonia is available via Biogas-E (Biogas-E, 2023b). However, since Wallonia is not part of the Belgian demo, this will not be described in further detail.

71 https://inagro.be/projecten/value4farm-sustainable-renewable-energy-value-chains-answering-farmers-needs
72 https://sempre-bio.com/
73 https://inagro.be/projecten/re-greenhouse
74 https://inagro.be/projecten/biogas-mambo
75 https://inagro.be/projecten/verhogen-integratie-he-de-landbouw
76 https://www.enerpedia.be/

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The CAP in Belgium is divided into two CAP Strategic Plans (European Commission, 2022a): one for Flanders and one for Wallonia. The two plans represent a total EU budget of over €2.8 billion, with €1.3 billion for Flanders and €1.5 billion for Wallonia. In the Flemish plan, income support and security are a key priority. In addition to direct payments, farmers will receive higher support for their first 30 ha of land. Investments to make farms more sustainable and resilient to market shocks are also encouraged with more than 35% of Flemish farmers to receive funding. To help address the environmental challenges related to its highly intensive agricultural model, Flanders allocates €185 million, more than half of its rural development budget, to environmental and climate-related objectives, such as reducing GHG emissions, increasing soil and water quality and strengthening biodiversity. The Flemish plan also aims to increase the area under organic farming to more than 30,000 ha. Thanks to specific support, it will also help 1,665 young farmers in setting up of their enterprises. Finally, CAP funding will help create more than 1,700 jobs in rural areas.

The Wallonian plan will set aside higher funding for direct payments with a redistribution payment for small and medium-sized farms. Farmers growing protein crops will receive coupled support with a budget of €17 million to encourage the protein autonomy of farms in the region. To achieve its environmental objectives, Wallonia dedicates 26% of its direct payments budget to eco-schemes, and 56% of its rural development budget to interventions protecting the environment, climate, and biodiversity. The agricultural area of the region under organic farming is expected to reach 18% thanks to CAP support. Rural development will also focus on generational renewal, gender equality, and social inclusion. The Wallonian plan will deploy funding to help 620 young farmers to set up their enterprises and will organise events and a dedicated working group to increase the participation of women in agriculture.

6.3 ITALY

6.3.1 National Agriculture and Renewable Energy Sectors

Agriculture

Italy is the 2nd highest EU 27 country contributing to agricultural production, with a diversified agricultural sector of crop/vegetable and livestock products (see Figure 33). As of October 2020, over 1.1 million agricultural companies were active in Italy, with 93.5% of which being managed as individual or family businesses. In terms of UAA, only a third of agricultural land is managed by land owners, while there is strong growth observed in the relative share of land managed for rent (ISTAT, 2021). In 2022, the overall share of the agricultural sector represented 2.2% of the GDP, generating a total value of €549 billion. (CREA, 2022).

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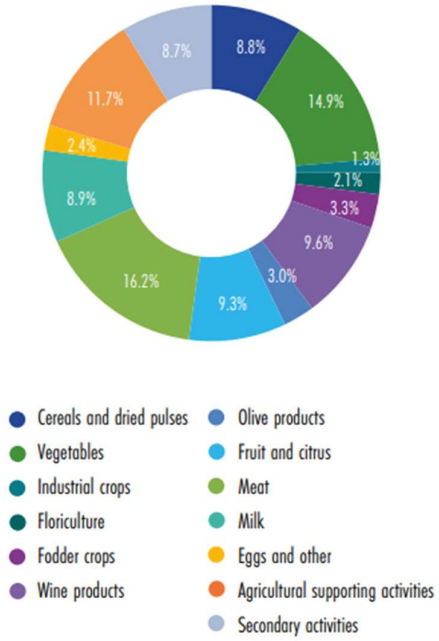

Figure 33. Production of goods and services at basic prices in the Agricultural sector - Values at current prices (€ mln). Italy, 2021. Source: (CREA, 2022)

Approximately 43% of the total land area is designated for agriculture, making Italy the 8th largest country in Europe, in terms of surface use for agricultural purposes. The UAA is 12,535,358 ha, with arable crops occupying 57%, permanent pastures and grasslands occupying 25%, and permanent crops (predominantly, olives, grapevines, orchards, and citrus fruits) occupying 17%. Arable land is cultivated in over half of Italian agricultural companies, i.e., more than 700,000, for a total surface area of over 7 million ha with an average farm size of 10 ha. 41.4% of the national surface area dedicated to arable crops is concentrated in Emilia-Romagna, Lombardy, Sicily and Puglia.

Among arable land, the most widespread crops are cereals for the production of grain (44% of the arable land area). In particular, durum wheat is grown in over 135,000 companies over an area of over 1 million ha. Agricultural woody crops are cultivated by ca. 800,000 companies for a surface area of 2.1 million ha and an average size of 2.7 ha. These crops are widespread throughout the national territory, but are mostly concentrated in Southern Italy. Permanent meadows and pastures are present on ca. 285,000 farms and occupy an area of 3.1 million ha. For this type of cultivation, Sicily is the region with the largest number of companies (43,000) and Sardinia the one with the largest dedicated surface area (698,000 ha) (ISTAT, 2021).

Under the current agricultural conditions, and given the subsidy system designed by the Italian government, the agricultural sector in Italy holds a point of leverage in the positioning of renewable energies.

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Energy Mix

In 2022, the Italian energy system was mainly based on natural gases (48.4%), followed by hydro (10.5%), solar energy (9.8%) and coal (9.6%) (see Figure 34). Italy's CO_2 emissions of 2022 equalled 310 Mt, representing ca. 0.9% of global emissions.

Figure 34. Electricity generation mix. Italy, 2022. Source: (IEA, 2023b)

Aligned with the targets of the EU, Italy's goal is to reach carbon neutrality by 2050, with 55% of renewable energy in electricity generation by 2030. In 2021, renewable energy sources covered 36% of overall national electricity consumption, ca. 20% of overall thermal consumption, and ca. 10% of transport energy consumption. In the electricity sector, there are approximately 1 million renewable energy plants in operation, with an installed power of 58 GW. As of 2022, hydropower is the largest source of renewable electricity generation, with solar PV following at 33.2% (see Figure 35). In the thermal sector, solid biomass, used mainly in the domestic sector, covers 64% of thermal consumption from renewable energy sources. In the transport sector, ca. 1.7 Mt of biofuels were consumed (GSE, 2023b).

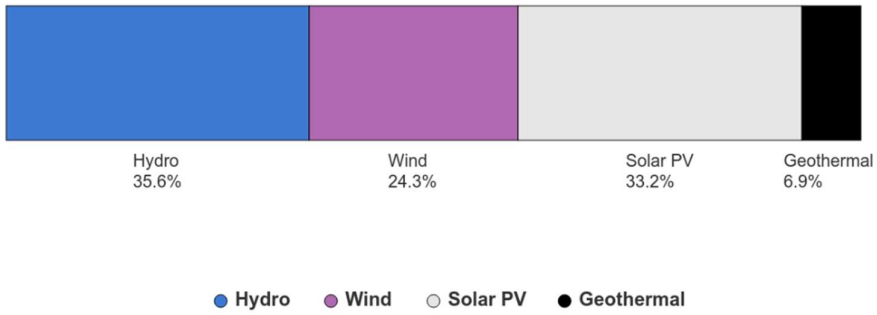

Figure 35. Renewable energy generation by source (non-combustible). Italy, 2022. Source: (IEA, 2023b)

Since 2000, the electricity generation by solar PV continues to increase, while hydro energy experiencing an overall decline (see Figure 36).

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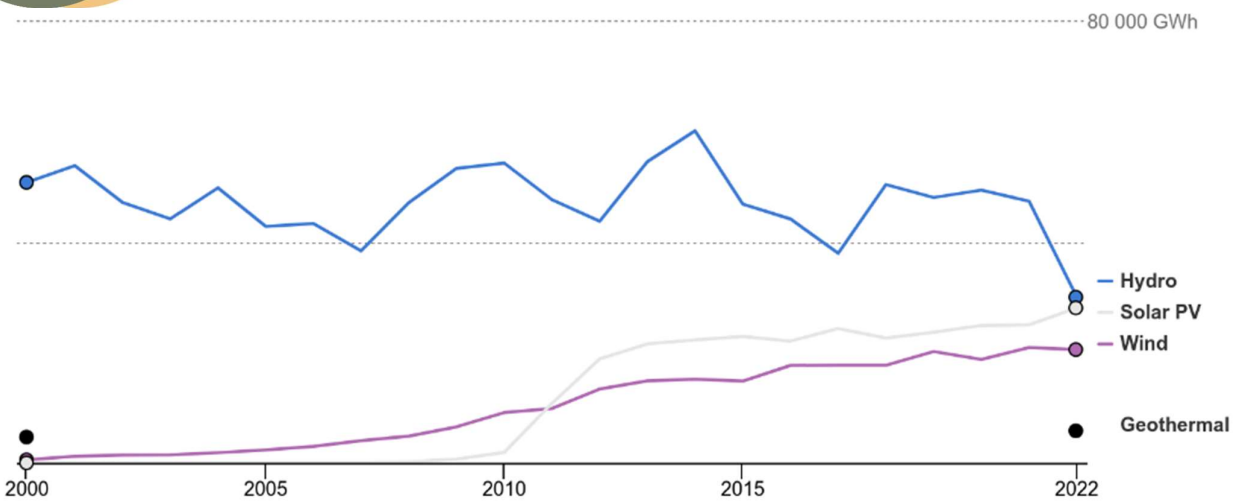

Figure 36. Evolution of renewable electricity generation (non-combustible). Italy, 2000-2022. Source: (IEA, 2023b)

6.3.2 Development of Agrivoltaics and Biogas/Biomethane

Biogas and Biomethane

Currently in Italy there are ca. 1,900 operating biogas plants, with a total installed capacity of ca. 1,300 MWe, making Italy the second largest biogas market in Europe after Germany, and the fourth in the word after Germany, China and the USA.

Most Italian biogas plants produce renewable electricity, benefiting from a FiT of 280 €/MWhel. Since the early 1990s, the incentive mechanism paths have seen an evolution, with initial government support introducing a green certificate system as the first official subsidy, which was followed by the 'all-inclusive' FiT (*tariffa incentivante omnicomprensiva*) from 2008 to 2012, In subsequent years, the subsidies have decreased compared to the initial support framework. However, the number of Italian biogas plants and their production has continued to grow at a constant rate from 2013 to the present day, mostly due to the Decree of July 6th, 2012 and its subsequent amendments and additions. The allocation of incentives within the decree's policy framework supported and was favourable for mostly small-scale plant size, i.e., facilities with a capacity below 300 kW.

The Legislative Decree 199/2021 acts as both the transposition of the REDII and the concrete measures within the Italian Recovery and Resilience Plan[77] (RRP) in the framework of the EU Recovery and

[77] https://reform-support.ec.europa.eu/what-we-do/recovery-and-resilience-plans_en

Resilience Facility[78] (RRF), which was introduced for coping with the impacts of the COVID-19 pandemic. It contains incentive schemes, which extend simplification measures related to the infrastructures for connecting biomethane to the grid. Thus far, it has contributed to steady growth and the sustainable biogas production model called BiogasDoneRight®.

The BiogasDoneRight® framework, developed by the Italian Biogas Consortium (*Consorzio Italiano Biogas* - CIB) and Italian farmers, makes better use of farmland by producing a rotation of 'energy crops' after feed crops, as well as waste and by-products created from the agro-industrial value chain. By applying the framework, the biogas sector ensures the overall sustainability of anaerobic digestion infrastructure, while benefitting from EC legislation that increases subsidies for bio-energy supply chains that comply with the criteria set out in the current RED for generating positive environmental externalities.

In addition to the large number of biogas plants and the presence of a mature biogas industry, Italy is home to many other important drivers for the biomethane sector, such as large numbers of natural gas vehicles and a wide extension of the natural gas grids. There are more than 1 million CNG and LNG vehicles, around 1600 CNG and LNG filling stations, around 40,000 km of natural gas transmission grids and 250,000 km of distribution grids. Nevertheless, despite this infrastructure, there are only 35 biomethane plants to date.

The 35 biomethane plants in Italy were built with the support of the Italian Biomethane Decree of March 2nd, 2018. This decree was originally planned to be in operation until December 31st, 2022, but its duration has been postponed by 12 months, until December 31st, 2023, according to the Ministerial Decree of August 5th, 2022. It provides subsidies only if the biomethane is used in the transport sector as a biofuel, to create 1.1 billion m^3 of biomethane per year.

The 35 biomethane plants have a capacity of around 350 million m^3 per year, which, as previously mentioned, is dedicated to the production of biofuels. Compared to the total production, ca. 80% of produced biomethane is injected into the natural gas, transport, or distribution grids. It is then sold, thanks to a mass balance mechanism, in compressed form in CNG fuelling stations connected to the gas network. The remaining 20% of the plants sell biomethane after a liquefaction process.

Currently in existing plants, the Organic Fraction of Municipal Solid Waste (OFMSW), with 60% of the total, is the most used feedstock for the production of biomethane, followed by agricultural by-products, with 35% of the total, and sewage sludge, with 5% of the total. Since the effective production cost of OFMSW, net of the other income of the treatment plant, is lower than the production cost of the other matrices, the Italian biomethane market was characterized by a strong prevalence of plants that use OFMSW. Furthermore, the prevalence of plants fed by OFMSW is due to the incentive mechanism introduced by the Biomethane Decree of 2018, not because there is a greater availability of OFMSW compared to agricultural waste. However, the decree provided the same incentive tariff for the production of biomethane from both OFMSW and agricultural waste and by-products. This and other barriers that influenced the Biomethane Decree of 2018 were corrected in the new Italian Biomethane Decree, MD n. 340 September 15th, 2022, published in the Official Gazette No. 251 of October 26th, 2022.

[78] https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en

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Agrivoltaics

In Italy, PV energy is the second most important source of renewable energy after hydroelectric. According to the last report of the national Energy Service System Operator (*Gestore dei Servizi Energetici* - GSE), the total installed capacity of PV, as of June 30th, 2023, exceeds 27 GW, with an increase of ca. 2.3 GW compared to the end of 2022 (+9%) (GSE, 2023a). As of June 30th, 2023, 31% of the total PV power installed in Italy is in ground-mounted systems and the remaining 69% is on covers, roofs, and buildings. In total, the ground-based PV parks occupy an area of ca. 16,000 ha, which represent ca. 0.1% of the total usable agricultural area.

The recent sharp increase of PV installation is both the consequence of the progressive reduction of the cost of producing PV energy and of the ambitious renewable energy targets set at the international and national level. According to the last revision of the Italian NECP, the target for installed PV energy in 2030 was raised by 55%, from 50 GW (according to the NECP 2019) to ca. 72 GW (according to NECP 2023). To achieve this target, the installed capacity will have to practically increase three-fold. The exponential increase of PV energy installations will exacerbate the conflicts within land use. A possible solution to mitigate the impact of PV expansion on land is the development and implementation of agrivoltaic systems.

According to a 2023 JRC report, considering to use an average agrivoltaic system with a power density of 0.6 MW/ha, the area required in Italy to reach the 2030 NECP PV capacity target of 72 GW, with only agrivoltaics, would be ca. 120,000 ha, which is 1.0% of the UAA, or 1.8% of arable land, or 3.6% of permanent grassland and meadow (Chatzipanagi et al., 2023).

6.3.3 National Policies

Biogas

The Italian system for biogas plants supports the production of electricity produced from biogas via CHP, with the scheme of FiT for newly installed biogas plants. The beneficiaries of the support are small scale biogas plants for electricity (up to 300 kWe of installed power). Plants with up to 100 kWe have direct access to support, while plants between 100 and 300 kWe must apply and be included in the Register for the Assignment of Available Power Shipment held by the GSE. In other words, the applicant does not need to wait for a confirmation or tender if the biogas plant is up to 100 kWe, but plants between 100 and 300 kWe must receive confirmation from the national organisation for renewable energy payments, i.e., the GSE, for enrollment in the Register. If enrollment is successful and a satisfactory position is reached, it is possible to require the support scheme after the construction of the plant. The plants must begin their operativity within 31 months from the date in which the successful outcome of the register procedure is communicated. Notably, in compliance with RED II, the selection procedure for providing plants with support schemes prioritises criteria regarding environmental protection over economic productivity.

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The economic support for plants built before Dec. 31st, 2012 (until the end of 2027) is 280 €/MWh of net electricity sold to the grid, which, considering a CHP efficiency of 38%, places the value of biogas at €106/MWh. The duration of such support is set for 15 years and no restrictions are imposed to limit the use of agricultural feedstock selection. Since 2013, incentives have been reduced to €233/MWh with a duration of 20 years for plants with a capacity of 300kW that base operations on a specified biomass feedstock. Feedstocks allowed for anaerobic digestion must belong to one of the following categories:

1. by-products listed in Table 1.A of Ministerial Decree of June 23rd, 2016 (e.g., crops residues, animal by-products, manure, etc.);
2. products listed in Table 1.B of Ministerial Decree of June 23rd, 2016 (e.g., some energy crops like sorghum, triticale, etc);
3. secondary crops (e.g., corn silage).

Plants must be fed by at least 80% of feedstocks categories 1 and 2, with category 1 comprising at least 70% of the total feedstock weight. The utilisation of feedstocks in category 3 cannot exceed 20% of the total. Moreover, plants must belong to the production cycle of crop and/or livestock farms, and be built by either farmers themselves or an association of farmers.

Within the urgent measures to overcome the energy crisis and inflation derived from energy import sanctions connected to the Russian-Ukrainian conflict, the range of by-products to produce digestate fertilizer from anaerobic digestion was expanded, including residues from food and agro-industrial activity. Furthermore, within an amendment of the so-called 'Price-Cutting Decree' *(Decreto-Legge TagliaPrezzi)*, agricultural plants are encouraged to increase the amount of bioenergy production sourced from biogas to meet the increased demand for renewable electricity.

For the list of all collected biogas policies in the Italian context, see Annex II - List of Identified Policy Instruments.

Biomethane

The regulatory framework in Italy for incentive measures aimed at the development and investment support of the biomethane sector is comprised of both the Biomethane Decree of 2018 and the new Biomethane Decree of 2022 (MD n. 340/2022). The Decree of March 2nd, 2018 on the "Promotion of the use of biomethane and other advanced biofuels in the transport field" defines a term of one year (December 31st, 2022 - December 31st, 2023) for plants that come into operation, according to Ministerial Decree of August 5th, 2022, which entered into force on August 19th, 2022. The new Biomethane Decree of September 15th, 2022, published in the Official Gazette No. 251 of October 26th, 2022, came into effect on October 27th, 2022 and defines the country's development of biomethane production and its integration into the natural gas grid until the end of June 2026. Because of the overlapping regulation framework, plants that have come into operation by December 31st, 2023 may decide for incentives provided in either the Biomethane Decree of 2018 (provided they meet the requirements set out in the Ministerial Decree of August 5th 2022) or 2022.

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The Biomethane Decree of 2018 is based on the allocation of the so-called Certificates of Release to Consumption of Biofuels (CIC), an incentive mechanism on which the aid system for biomethane promotion has been based. The GSE updated the issued CIC for the reference period of January – April 2022. Such certificates are allocated by the GSE to fuel suppliers, obligating the blending quota of biofuels. Since biomethane producers have no quota of fossil fuel for consumption, such CIC are sold by biomethane producers at a fixed or minimal price to those subjects (e.g., fuel suppliers) who release non-renewable fuels.

As a basic rule, one CIC is assigned to every 10 GCal of biomethane produced and every 5 GCal (double counting) when the biomethane is considered 'advance biomethane', i.e., produced from either OFMSW, by-products, or algae (outlined in Annex 3 to the Ministerial Decree of October 10th, 2014). For the double counting to be recognized when biomethane is produced in co-digestion with other products, the latter cannot exceed 30% by weight and the advanced biomethane qualification will be recognized only at 70% of production. The principle of co-digestion also applies in the case of conversions and/or increases in power of existing plants.

A direct withdrawal mechanism for CICs by the GSE is instituted for advanced biomethane. Upon the request of the producer, the GSE withdraws biomethane for distribution through the network. The withdrawal of the biomethane by the GSE takes place at a price equal to that of the Spot Market for Gas (MPGAS) reduced by 5%, then the GSE recognises the value of the corresponding CIC, assigning each certificate a value of €375. The producers of advanced biomethane also have the possibility to request from the GSE to be excluded from the physical delivery of the biomethane produced if they sell their production independently for the consumption in the transport sector. In such a case, the incentive will coincide with the value of the corresponding CIC, valued by the GSE at €375. Following this ten-year period, the producer should have access to the ordinary method of valuing the CIC for the remaining period of the law, namely through the private sale to obliged parties. To help the CIC trade market, the Italian Power Exchange (IPEX) must set up an organized exchange platform that can eliminate the criticisms that characterize the current CIC exchange system.

The new Italian Biomethane Decree (MD n. 340 September 15th, 2022), pursuant to the Mission 2, Component 2, Investment 1.4, (concerning the "development of biomethane according to criteria to promote the circular economy") establishes incentives mechanisms, allocating €1.73 billion, partially funded from the RRF, and combines assets and reforms for additional biomethane production. Moreover, the incentive tariffs within the decree have an estimated budget of €2.8 billion over a 15-year operational period. New measures aim at promoting investments in new plants or reconverted plants (from biogas to biomethane) and encourage the development of biomethane and its injection into the national gas grid for use also in sectors other than transport (e.g., heating for industrial, tertiary, and residential sectors).

The new decree applies to new built plants using agricultural or waste feedstocks as well to those revamping agricultural biogas power plants. To receive support, the decree specifies a mandatory deadline (June 30th, 2026) to complete the work associated to the new construction or conversion plant. Subsidies are awarded based on power quotas, through competitive tendering schemes in compliance with sustainability criteria defined in REDII (e.g., reduction of GHG emissions).

The introduction of the new decree provides innovations and extensive modifications regarding new incentives. Specifically, Article 3 of the new biomethane decree foresees incentive consisting of two modes of compensation, i.e., the capital grant contribution *(contributo in conto capitale*) and FiTs. Capital

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contribution covers up to a 40% capital incentive of the eligible investment costs for the construction or reconversion of plants. The capital incentive for plant type A (agricultural) and B (organic waste) must comply with values indicated in Table 5.

Type	(m³ /h)	€/m³/h (new)	€/m³/h (reconversion)	%
A	<100	33,000	12,600	40
	100-500	29,000	12,600	40
	> 500	13,000	11,600	40
B	Any	50,000		40

Table 5. Mandatory output values for agricultural (A) and organic waste (B) biomethane plants to receive capital grant contributions under the new Italian Biomethane Decree of 2022. Source: CIB

The FiTs, i.e., all-inclusive tariffs, within the new decree are relevant for plants with a production capacity equal to or lower than 250 m^3/h that feed biomethane into grids with a third-party connection obligation. The obtainment of the incentive, including the economic value of the sale of gas as well as the value of the GoO, are recognized and disbursed by the GSE.

Alternatively, FiPs are also included in the new decree's incentive scheme, being calculated by considering the reference tariff (€/MW h) for plant type A (agricultural) and B (organic waste) (see Table 6) in accordance with the methods set out in Article 7 and Annex 2 of the Biomethane Decree.

In this case, the payable tariff derives from the difference between the reference standard tariff, the average monthly price of natural gas, and the average monthly price of GoOs, which serve to prove the origin of renewable gas used.

Type	(m³ /h)	€/MWh
A	<100	115
	>100	110
B	Any	62

Table 6. Mandatory output values for agricultural (A) and organic waste (B) biomethane plants to receive FiPs under the new Italian Biomethane Decree of 2022. Source: CIB

A significant growth in the sector is expected in the coming years due to both the new decree and the changes made to the 2018 decree in the last year, which was active until the end of 2023. Italy can now achieve a production of 3.5 billion m^3 of biomethane by 2027 and a production of 6.5 billion m^3 of biomethane by 2030. The contribution of OFMSW and other sectors (e.g., sewage plants, landfill, etc.) could be equal to 1.5 billion m^3 of biomethane per year. The rest will be produced from agricultural biomethane.

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In order to achieve the indicated targets, the pillars for the development of the Italian agricultural biomethane potential are:

i) limited use of primary crops (less than 200,000 ha, 3% of the Italian UAA in arable land in any case lower than the surface area once allocated to set aside);
ii) increasing the use of secondary crops;
iii) growing use of livestock manure in anaerobic digestion;
iv) growing use of agricultural residues and agro-industrial by-products.

The final use of biomethane will not be exclusively dedicated to the production of biofuels but also to other sectors, especially those that are difficult to electrify. It is expected that the production of biofuels from biomethane will represent ca. 25% of all biomethane production.

To complete the description of the Italian biomethane scenario it is essential to describe the scenario of the bioLNG sector. The bioLNG sector produced from biomethane experienced a rapid and significant growth in the last four years due to the support framework of the same decrees of gaseous biomethane. It is estimated that the number of bioLNG plants will be more than 30 in 2024 with a production capacity of ca. 100,000 t per year.

For the list of all collected biomethane policies in the Italian context, see Annex II - List of Identified Policy Instruments.

Agrivoltaics

The reference legislation for agrivoltaic systems in Italy is the Legislative Decree 199/2021, which implements the EU RED II, focused on promoting the use of renewable energy. This decree establishes the guidelines and fundamental requirements for the development and operation of agrivoltaic systems.

On February 24th, 2023 the Decree Law no. 13/2023 was published, which dictates new provisions for the implementation of the national RRP. This decree has introduced important news relative to the installation of PV and agrivoltaic systems. In particular, the decree has simplified the procedures needed for the authorisation for building an agrivoltaic plant, particularly when the farmer is directly involved.

Another key document for the development of agrivoltaics in Italy, is the *Guidelines in the Field of Agrivoltaic Systems* published by the Ministry of Energy Transition (MiTe) in June 2022. It sets a clear and concrete definition of agrivoltaics together with a standard for agrivoltaic systems. Furthermore, the guidelines from the MiTe contain a general framework on agricultural productivity, energy costs, and PV electricity production. They identify the characteristics and requirements of agrivoltaic systems, how they should be monitored, the reward characteristics of the agrivoltaic systems, and an analysis of the investment costs of agrivoltaic systems. According to the guidelines, agrivoltaic systems are PV systems that allow the continuity of agricultural and pastoral activities on the site where the agrivoltaic system is installed, while ensuring production of renewable energy. Agrivoltaics constitute virtuous and improved solutions compared to standard PV systems.

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The guidelines also define standards for an 'advanced agrivoltaic system', which would be eligible for financial support through the national RRP. Specifically, the advanced agrivoltaic system:

i) adopts innovative integrative solutions with an assembly of the modules elevated from the ground, involving the rotation of the modules themselves in such a way as not to compromise the continuity of agricultural and pastoral cultivation activities, while also possibly allowing the application of digital and precision agriculture;
ii) envisages the simultaneous creation of monitoring systems that verify the impact of the PV installation on crops, water saving, agricultural productivity of different types of crops, the continuity of the activities of the involved farms involved, the recovery of soil fertility, the surrounding microclimate, and overall resilience to climate change.

The requirements that agrivoltaic systems must comply with in order to receive incentives from the current regulatory framework are identified by the following guidelines.

- REQUIREMENT A: The system is designed and implemented in such a way as to adopt a spatial configuration and appropriate technological choices, which enable the integration between agricultural activity and electricity production and enhance the production potential of both subsystems. In particular, requirement A1 states that in an agrivoltaic system must have at least 70% of the surface intended for agricultural activity, in compliance with Good Agricultural Practices (GAP) outlined by the Food and Agriculture Organization (FAO). Requirement A2 states that in order not to limit the use of particularly innovative and efficient solutions, it is considered appropriate to limit the percentage of the surface of the agrivoltaic system which is occupied by PV modules to a maximum of 40% (ultimately limiting the density of PV panel installation and therefore the maximum shading present in the agrivoltaic system).
- REQUIREMENT B: The agrivoltaic system is operated, during its technical life, in such a way as to guarantee the synergistic production of electricity and agricultural products and not to compromise the continuity of agricultural and pastoral activity. In particular, requirement B1 requests that the agricultural crops cultivated under agrivoltaics are those typically cultivated in the farm or are improved, and that the yield level is maintained (however a minimum yield level is not stated)- Requirement B2 indicates that electric production in agrivoltaics cannot be lower than 60% of that obtained from a reference PV system.
- REQUIREMENT C: The agrivoltaic system adopts innovative integrated solutions with modules elevated from the ground, aimed at optimizing the performance of the agrivoltaic system both in energy and agricultural terms. In particular, in elevated agrivoltaics the modules should have a minimum height from the soil of 2.1 m in the case of an agrivoltaic system with crops, and 1.3 m in the case of animal husbandry.

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- REQUIREMENT D: The agrivoltaic system is equipped with a monitoring system that enables the verification of the impact on crops, water saving, agricultural productivity for the different types of crops, and the continuity of the activities of the agricultural companies involved.
- REQUIREMENT E: The agrivoltaic system is equipped with a monitoring system which, in addition to complying with requirement D, allows for the verification of the recovery of soil fertility, the microclimate, and resilience to climate change.

In 2023, two other documents have been published that, starting from the Italian guidelines, provide a more detailed interpretation on agrivoltaic development. They are *UNI/PdR 148:2023 Agri-voltaic systems - Integration of agricultural activities and photovoltaic implants* and *CEI PAS 82-93 Agrivoltaic sytems*. Furthermore, in December 2023, The Italian Minister of the Environment and Energy Security has approved, signed, and transmitted to the Court of Auditors (after the approval of the EC) a decree that promotes the construction of innovative agrivoltaic systems. The objective of the decree, envisaged by the RRP, is to install at least 1.0 GW of agrivoltaic systems by June 30th, 2026 through granting, from RRP funds, capital contributions up to a maximum of 40% of the eligible construction costs, and an incentive tariff on the production of net electricity fed into the grid.

6.4 POLAND

6.4.1 National Agriculture and Renewable Energy Sectors

Bioeconomy

Poland's bioeconomy and renewable energy landscape are strongly conditioned by geography. Poland's landscape varies considerably from the sandy coastline of Baltic Sea in the north to the mountains in the south. Most of the country consists of plains and low hills. Around 60% of the country's surface is agricultural land and 30% is forest (Bio-based consortium, 2023).

Poland's bioeconomy contributed over €146.8 billion in turnover in 2019 (Jarosz & Faber, 2023). The overall production volume of the Polish bioeconomy in 2014 amounted to €82 billion, which is 10% of the total production volume of the Polish economy (Woźniak & Twardowski, 2018). The sector generated ca. 5% of the Gross Value Added (GVA) of EU, employed ca. 2.5 million people (15% of total workforce), and contributed 15% and 10% of total exports and imports, respectively (Nowak et al., 2021).

The strong drivers of Poland's bioeconomy are agri-food, forest-based, and chemical industries. Despite the relatively low innovation level in bio-based activities, innovation performance has grown faster than the EU average. Furthermore, the abundance of biomass feedstock from primary and secondary sectors provides a significant basis for expanding bio-based activities. The pharmaceutical industry is also rising, making Poland the leading country in this field in Central-Eastern Europe (Bio-based consortium, 2023).

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Agriculture

Polish agriculture holds the fifth position in EU27 by value, behind France, Italy, Spain, and Germany, and just ahead of the Netherlands. The gross production value (GPV) of agriculture in 2020 was €26.7 billion, with a GVA of €11.7 billion. In 2022, agriculture contributed around 2.2% to the GDP of Poland. Agricultural lands consist of 60% of the country's area. Polish agriculture is characterized by fragmentation: slightly over half of the holdings (51%) are smaller than 5 ha, while only 5.2% occupying an area larger than 30 ha. Plant cultivation is responsible for 40% of the total agricultural production (by value), while livestock accounts for ca. 55% (Bio-based consortium, 2023).

Agricultural land is mainly occupied by wheat, barley, oats, potatoes, colza, vegetables and fruit. This creates great opportunities for the development of a bioeconomy based on this biomass (Council of Ministers, 2019).

Renewable Energy

In 2022, total energy consumption was 1198.3 TWh. The highest share within energy consumption was coal and oil (see Figure 37) (Ritchie & Rosado, 2024). The share of renewable energy in primary energy in 2022 was ca. 9.4% and it sharply increased in last years, mainly due to the change in the definition of small plant installations, i.e., the increase in the upper limit of range of power to 1MW (see Figure 38) (Ritchie & Rosado, 2024). The share of renewable energy in gross final energy consumption was 16.9% in 2022.

Thanks to government support and strong consumer interest, Poland is one of the fastest-growing European markets for rooftop solar. The government has introduced a well-designed and ambitious offshore wind programme, and is planning to build its first nuclear reactor by 2033 (IEA, 2022c).

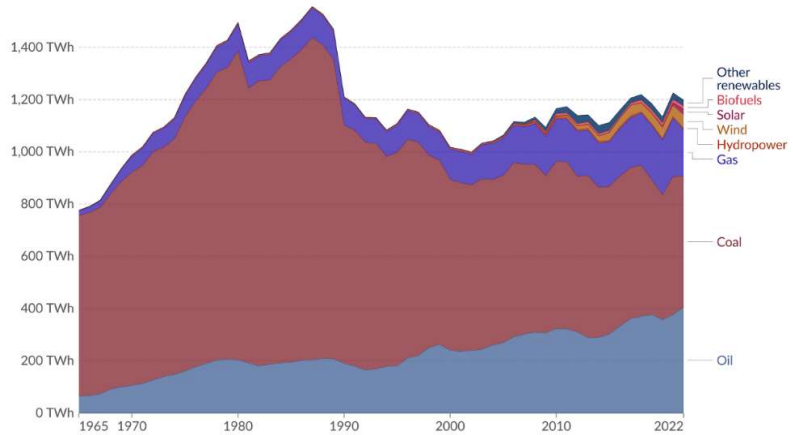

Figure 37. Primary energy consumption by source. Poland, 1965-2022. Source: (Ritchie & Rosado, 2024)

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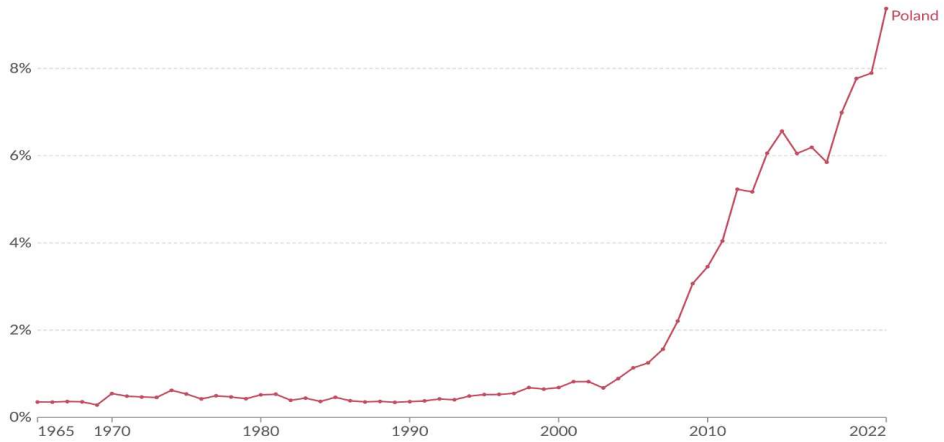

Figure 38. Share of primary energy from renewable sources. Poland, 1965-2022. Source: (Ritchie et al., 2024)

Regarding electricity production, ca. 179 TWh of electricity was produced in Poland in 2022. The use of coal is still high but successively decreases. In 2022, the electricity production from coal (hard coal and lignite) was 71.1%, and renewable energy sources was ca. 21.2% (see Figure 39) (Biuro Analiz PFR S.A., 2023). Partial data shows that the increase in 2023 is the largest so far, and the share of renewables in electricity production is estimated at ca. 27%. Approximately 74% of renewable energy comes from two sources: wind energy (53%) and solid biofuels (21%). Nonetheless, the importance of PV increased significantly from 1% in 2018 to 13% in 2021 (see Figure 40) (Statistics Poland, 2023). According to the IEA, 1288 GWh of electricity was produced out of biogases in 2021 (IEA, 2022c).

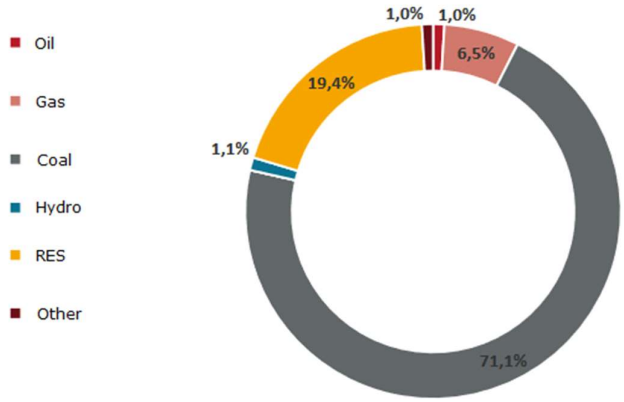

Figure 39. Electricity production divided into sources (share in %). Poland, 2022. Source: (Biuro Analiz PFR S.A., 2023)

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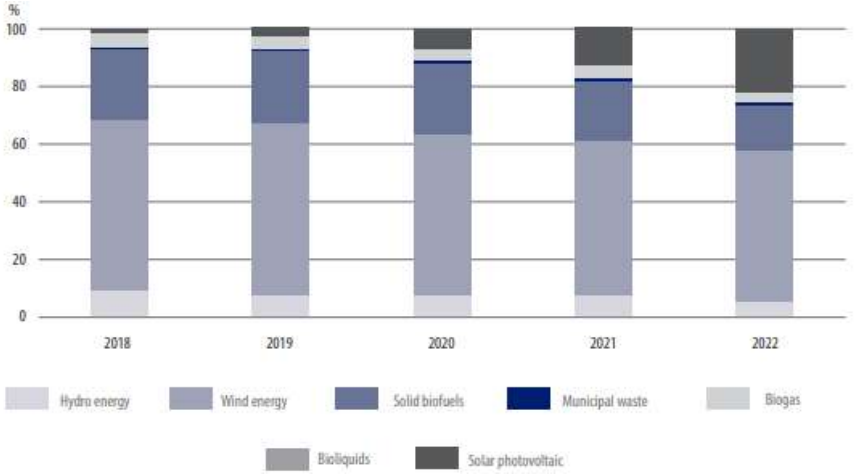

Figure 40. The share of renewable energy carriers in electricity production. Poland, 2018-2022. Source: (Statistics Poland, 2023)

Since 2017, most of Poland's energy consumption is related to transport, followed by residential and industry sector (see Figure 41) (IEA, 2024). The net primary energy consumption in agriculture in Poland was 155,547 TJ in 2021, which is only 4,7% of total energy consumption. The most important energy carrier is oil and petroleum products (64.4%). Energy from renewables, i.e., primarily biofuels and waste, accounted for ca. 15.5% of the total energy consumption in agriculture and forestry (IEA, 2024).

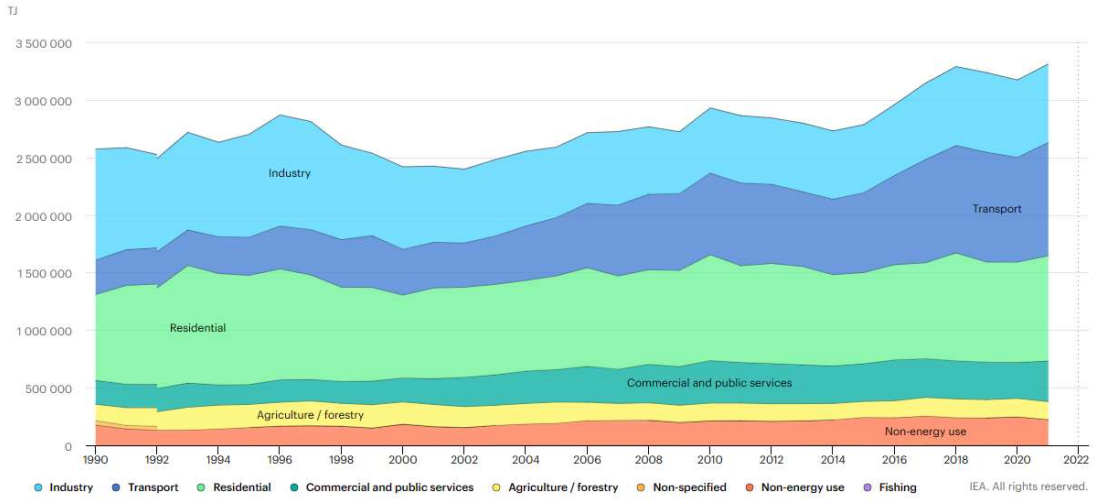

Figure 41. Total final energy consumption by sector. Poland, 1990-2022. Source: (IEA, 2024)

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6.4.2 Development of Agrivoltaics and Biogas/Biomethane

Biogas and Biomethane

As of April 2023, the total number of biogas plants in Poland is currently 383 installations, of which 148 are agricultural biogas plants, 194 are municipal biogas plants, and 41 are micro biogas plants producing energy mainly for their own use. Their total power is around 280 MW, and electricity production is ca. 2,352 TWh per year. Due to the relatively high fragmentation of agricultural production in Poland, the installed capacity of most installations does not exceed 1 MW. The share of biogas in the overall structure of obtaining electricity from renewable sources is ca. 2.5% (Dach et al., 2023).

Despite so many investment announcements, great potential, and needs, the biomethane market still does not exist. However, many installations for the production of biomethane are currently in preparation. It is likely that the first operating biomethane plant in Poland will be an investment made at the Brody Experimental Farm within the framework of the 'Innovative Biogas Plant' competition under the auspices of the National Center for Research and Development and the Poznań University of Life Sciences. The National Center for Research and Development, with European funds under the Smart Growth Program, has taken specific actions to support the development of innovative technologies for the biogas, biomethane, and digestate sector. Based on the amount of biomass in Poland, it is estimated that the potential for biogas and biomethane production is 15 and 8 billion m^3 per year, respectively.

Agrivoltaics

Currently in Poland, there is no suitable agrivoltaic regulatory environment, which would provide for dual use of land. It is the main barrier to the development of agrivoltaics in Poland. An amendment to the law on spatial planning is needed to add the possibility of dual land use, and to eliminate the requirement to exclude land from agricultural production for agrivoltaics. This amendment would allow for direct subsidies to be maintained and tax increases to be avoided. Unfortunately, for the time being, the installation of PV panels is possible only on land excluded from agricultural production (Polish Photovoltaic Association, 2023).

There is the Polish Photovoltaics Association in Poland, which includes a special group for agrivoltaic issues. Moreover, agrivoltaic technologies are known in Poland, and there are also domestic companies that deal with their development. There are individual PV farms where sheep are grazed or flower meadows are established for bees. One of the first experimental agrivoltaic farms was established in Zgorzelec by the Zgorzelski Energy Cluster. In 2022, wild garlic was grown there under panels with postive results.

According to a 2023 JRC report, considering to use an average agrivoltaic system with a power density of 0.6 MW/ha, the area required in Poland to reach the 2030 NECP PV capacity target of 30 GW, with only agrivoltaics, would be ca. 50,000 ha, which is 0.3% of the UAA, or 0.5% of arable land, or 1.6% of permanent grassland and meadow (Chatzipanagi et al., 2023).

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Digestate Use

In Poland, digestate can be used as fertilizer after meeting the requirements for the minimum content of fertilizing components and organic matter, and limited content of impurities (heavy metals, pathogenic organisms, and parasite eggs). Until 2023, after amendments to the act on fertilizers and fertilization, post-digestion products became the third group of fertilizer preparations (along with fertilizers and plant growth promoters) with the same legal status. Therefore, digestate is tested to ensure environmental safety, but without the need to go through a complex procedure before being placed on the market (Dach et al., 2023). During the agricultural biogas production in 2022, over 4.3 Mt of digestate were produced (CIRE, 2023).

6.4.3 National Policies

CAP Strategic Plan

At the end of 2023, Poland presented its CAP Strategic Plan. One of main goals is reducing dependence on synthetic fertilizers and increasing energy production from renewable sources without harm to food production (European Commission, 2023e).

Road Map towards the Transition to Circular Economy

Poland participates in the macro-regional bioeconomy initiative BIOEAST, being developed by Central and Eastern European countries. The national Bioeconomy Strategy Concept Paper is developed in the framework of the BIOEAST National Platform and the BIOEASTsUP project, coordinated by the Institute of Soil Science and Plant Cultivation (IUNG). Poland's Council of Minister's adopted the *Roadmap towards the Transition to the Circular Economy* (Council of Ministers, 2019). The roadmap is a strategic document that determines the necessary actions to be taken by the public administration in order to create the framework for a circular economy. The bioeconomy is one of the pillars of this roadmap, with tasks to be carried out by the Government for bioeconomy development.

Long-term Development Strategy for Poland 2030 and Mid-Term Development Strategy for Poland 2020 (including the perspective up to 2030)

In Poland, there is no single, complex, and strategic document dedicated to the bioeconomy. Issues related to the development of the bioeconomy and renewable energy are incorporated mainly in three of nine integrated strategies, which constitute the Long-term Development Strategy for Poland 2030 (Ministry of Administration and Digitalization, 2013) and the Mid-Term Development Strategy for Poland 2020, which was updated and replaced by The Strategy for Responsible Development for the period up to 2020

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(including the perspective up to 2030) (Ministry of Funds and Regional Policy, 2017). These strategies include the Strategy for Sustainable Development of Rural Areas, Agriculture and Fisheries (Ministry of Agriculture and Rural Development, 2019) and the Strategy of Energy Safety and Environment (now replaced by Poland's Energy Policy until 2040) (Ministry of Climate and Environment, 2021).

Strategy for Sustainable Development of Rural Areas, Agriculture and Fishers 2030

The main aim of this strategy is the economic development of the countryside and the sustainable increase in the income of its residents, while limiting economic, social, and territorial stratification and improving the environment. The planned measures until 2030 include:

i) supporting the sustainable development of small, medium and large farms;
ii) making greater use of the potential of the agri-food sector than before through the development of new skills and competencies of its employees, as well as through the use of the latest technologies in production and the application of digital solutions, and creating conditions for the creation of innovative products;
iii) building the competitive position of Polish food on foreign markets, the hallmark of which will be high quality and reference to the best Polish traditions, as well as the adaptation of agri-food products to changing consumption patterns (e.g., the growing interest in organic food);
iv) conducting agricultural and fishing production with respect for environmental protection principles and adapting the agri-food sector to climate change, including, among other things, the availability of water;
v) creating conditions for improving the professional mobility of rural residents and their use of opportunities for development and re-skilling, resulting from the emergence of new economic sectors, i.e., the bioeconomy.

Poland's Energy Policy until 2040

Poland's Energy Policy until 2040 (PEP2040) is a compass for businesses, local governments, and citizens in the transformation of the Polish economy towards a low-carbon direction.

In PEP2040 strategic investment decisions are made to take advantage of the country's economic, raw material, technological, and human resource potential, as well as to create a lever through the energy sector for the development of the economy, fostering an equitable transformation.

In 2040, more than half of the installed capacity will be zero-carbon sources. A special role in this process will be played by the implementation of offshore wind power and the launch of a nuclear power plant into the Polish electricity system. These will be two strategic new areas and industries that will be built in Poland. This is an opportunity for the development of domestic industry, specialized human resource competencies, new jobs, and the generation of added value for the national economy. Parallel to large-scale energy, distributed and civic energy will develop based on local capital. The transformation also requires increasing the use of renewable energy technologies in heat generation and increasing the use of alternative fuels in transportation, including the development of electromobility and hydrogen mobility.

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Poland's National Energy and Climate Plan 2021-2030

Poland's NECP targets for 2030 include:

i) 7% reduction in GHG emissions in non-ETS sectors compared to 2005 levels;
ii) 21-23% share of renewable energy source in gross final energy consumption,
iii) 14% share of renewable energy sources in transport,
iv) 1.1% average annual increase in the share of renewable energy sources in heating and cooling;
v) 23% increase in energy efficiency compared to PRIMES2007 projections;
vi) 56-60% reduction of coal's share of electricity generation.

The NECP presents the goals, policies, and actions for the realization of the 5 dimensions of the EU Energy Union, i.e., energy security, internal energy market, energy efficiency, decarbonization, and research, innovation, and competitiveness (Ministry of Climate and Environment, 2019).

Act on Energy Law

The Act on Energy Law (No. 54, item 348, 1997) specifies Poland's energy policy, i.e., the principles and conditions for the supply and use of fuels and energy (including heat), the operation of energy enterprises, and the authorities competent in matters of fuel and energy management. Its aim is to define the conditions necessary for sustainable development of the country, ensuring energy security, economical and rational use of fuels and energy, developing competition, considering environmental protection requirements, and implementing obligations arising from international agreements. The energy law is the legal basis for increasing the use of energy from renewable energy sources by imposing an obligation on energy companies to allow renewable energy entities to connect to the grid. The act also involves municipal governments in the implementation of the state's energy policy by implementing it in their own areas.

Special Biogas Act

The act on facilitating the preparation and implementation of investments in agricultural biogas plants, as well as their operation, is a special act prepared by the Ministry of Agriculture and Rural Development especially for agricultural biogas plants. The main objectives are to facilitate the investment process, increase the use of local substrate potential, and allow for better management of digestate, which finally is no longer treated as waste. Of particular importance to the industry are provisions to reduce the waiting time for the issuance of network connection conditions and to change the definition of some substrates from waste to by-product.

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Support Systems for Electricity Production from Renewable Sources

The catalog of instruments for financing and supporting renewable energy investments currently available in Poland (Przygodzka et al., 2023) includes:

i) a subsidy system for investments in renewable energy sources;
ii) funds allocated at the central and local levels;
iii) EU funds;
iv) funds from the National Fund for Environmental Protection and Water Management (NFOŚiGW) and its provincial branches;
v) preferential loans and credits granted by the banking sector;
vi) large investment loans (bank consortiums) for the construction of power plants producing electricity from renewable energy sources;
vii) public-private partnership (PPP)
viii) leasing;
ix) green bonds;
x) share capital;
xi) tax relief for individual clients (subsidy exemption from personal income tax and thermal modernization relief) and renewable energy producers (VAT and tax exemption excise duty).

Moreover, the current support system consists of CoOs, i.e., blue certificates for agricultural biogas and green certificates for other renewables, the auction system, Power Purchase Agreements (PPAs), which are long-term power supply contracts between a producer and its consumer or seller, as well as support in the form of FiPs and FiTs for biogas and hydropower only. The amount of support under FiP and FiT is determined by the reference prices announced each year by the President of the Energy Regulatory Office (Dach et al., 2023).

Another step taken by the government to increase biogas production is the 'Energy for Countryside' program announced in January 2023, under which farmers and energy cooperatives have the opportunity to obtain a loan or subsidy for the construction of biogas plants from 10 kW to 10 MW.

6.4.4 Regional Policies (Lublin)

The Lublin (*Lubelskie*) voivodeship is one of the 16 polish voivodeships. It is located in eastern Poland. It is one of the least urbanized regions. Its administrative structure consists of 213 communes, including 20 urban communes, 170 rural communes, and 23 urban-rural communes. The Lublin voivodeship has a population of ca. 2.2 million people. The average population density is 86 people/km^2 (compared to 122 people/km^2 in Poland). Rural residents constitute 53.7% of the region's population (compared to 39.1% in Poland). The employment structure in the Lublin voivodeship is characterized by a dominant share

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working in the agricultural sector. The Lublin region has the largest amount of the highest quality soil in Poland.

The main area of economic specializations in Lublin is the bioeconomy, which is associated with the development of renewable energy sources. Renewable energy sources, especially solar energy and biomass, offer great opportunities for the region's development. It is estimated that in the Lublin voivodeship, the annual energy potential of agricultural waste is nearly 1 Mt, which is equivalent to ca. 15 PJ of energy. Estimated reserves of land that can be used for energy crop cultivation without competition for food production is ca. 208,000 ha, which has the energy potential of 11 PJ. Almost the entire Lublin Voivodeship is located in the area recognized in Poland as privileged in terms of solar potential for useful energy. This potential is determined by the annual solar power density and varies from ca. 950 to ca. 1050 kWh/m^2. Another parameter showing the potential for solar radiation is the solar insolation, i.e., the amount of time the sun directly illuminates an area, which for Lublin is ca. 1600 hours annually (Board of the Lublin Voivodeship, 2015).

According to the biogas map of Poland developed by the Biomass Media Group, there are 12 agricultural biogas plants, 7 municipal biogas plants, and 1 micro biogas plant in the Lublin region (see Figure 42) (Biomass Media Group, 2023).

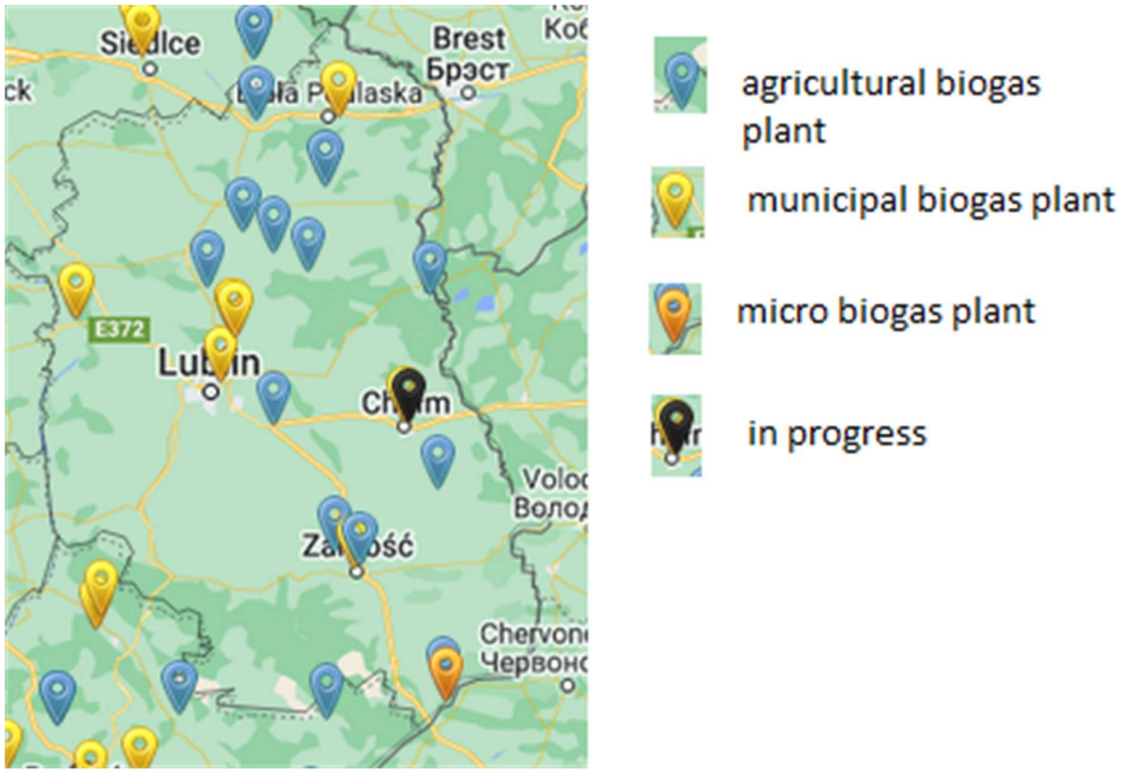

Figure 42. Biogas plants in Lublin voivodeship. Source: (Biomass Media Group, 2023)

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Development Strategy of the Lublin Region until 2030

The main strategic document of the Lublin Voivodeship is the Development Strategy of the Lublin Region until 2030 (Board of the Lublin Voivodeship, 2021). In this document, four strategic purposes and nineteen operational tasks were identified. The key goal is to make the most of agricultural potential, develop towns and cities, improve quality of life and enhance competitiveness in the national and international environment.

The objectives particularly relevant to the bioeconomy, renewable energy, and the VALUE4FARM project include:

i) strengthening the innovation and technological advancement of agricultural holdings;
ii) improving the size and organisational structure of farms;
iii) soil protection, i.e., limitation of the use of chemical fertilisers and plant protection products;
iv) improving the energy efficiency of farms;
v) increasing the production and use of energy from renewable sources;
vi) developing a programme defining the directions of energy development in the voivodeship;
vii) developing industries using agricultural raw materials for non-food purposes;
viii) increasing the energy efficiency of production processes and the generation and use of energy from renewable energy sources;
ix) developing cooperation in the agri-food sector by strengthening cooperation between the R&D sector and the production and processing sector, including in particular the use of agricultural raw materials for non-food purposes;
x) strengthening links and functional systems by sustainable development of technical infrastructure systems provides for the development of the energy generation, distribution and storage and transmission monitoring system including modern solutions, as well as the development of the national gas system and local systems using natural gas (underground gas storage) and biogas storage facilities;
xi) preparing a plan setting out the direction for the development of energy in the voivodeship. (Considering conventional energy, the use of renewable energy sources, and the development of a waste management plan are selected directions of activities of the voivodship local government);
xii) developing of urban functional areas by integrating environmentally friendly transport systems in urban functional areas, including intervention directives for infrastructure for electromobility, supporting activities, climate change adaptation, and disaster resilience, as well as the reduction of pollutant emissions.

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Lublin's Clusters

The Lublin region has a long tradition in clustering. Cluster activities promote and develop new innovative technologies related to agriculture, including eco-food (e.g., Organic Food Valley Cluster), eco-energy, including renewable energy (e.g., Lubelski Eco-Energy Cluster), aviation (e.g., Aviation Valley), as well as the Eastern Cluster ICT (Board of the Lublin Voivodeship, 2015).

Lublin Eco-Energy Cluster involves entities in the field of renewable energy (solar, wind, hydro, and geothermal), as well as production and use of biomass for energy purposes. Prominent cluster partners include producers of machinery and equipment and producers of pellets and briquettes. The partners are also designers and contractors of biogas plants, wind farms, solar farms, small hydropower plants, and electricity networks. Another group of entities are engaged in the waste management industry, IT solutions for the renewable energy industry, higher education and research, as well as energy efficiency and energy-saving construction. The coordinator of the cluster is the Foundation for Lubelskie Development. The Lublin Eco-Energy Cluster's mission is to support all activities related to the Lublin Voivodeship's potential to develop and implement technological innovations, as well as the production, processing, and popularisation of renewable energy sources in the region (Foundation for Lubelskie Development, 2024).

As part of the Lublin Eco-Energy Cluster, there are two consortia: the Lublin Energy-Efficient House and Lublin Energy Agency. The aim of the Lublin Energy-Efficient House is the successful development and dissemination of key product of the cluster, i.e., an ecological energy-efficient house. The Lublin Energy Agency was established to support local governments and entrepreneurs from the Lublin Voivodeship in the organization and implementation of projects aimed at improving energy efficiency and energy production from renewable sources. The agency identifies and promotes good practices related to the implementation of projects using renewable energy sources to produce electricity and heat as well as activities to improve energy efficiency by local governments and entrepreneurs. It also carries out activities aimed at raising awareness of the region's residents about the benefits of technologies focused on renewable energy generation and energy savings within electricity and heat.

Support Instruments for the Development of Renewable Energy Sources in Lublin Voivodeship

The Lublin Voivodeship is a leader among Polish voivodeships in obtaining funds for the development of renewable energy (see Figure 43). The main support instruments are the European Regional Development Fund and Operational Program Infrastructure and Environment. Thus far, PV installations have received most of the funds (Przygocka et al., 2023).

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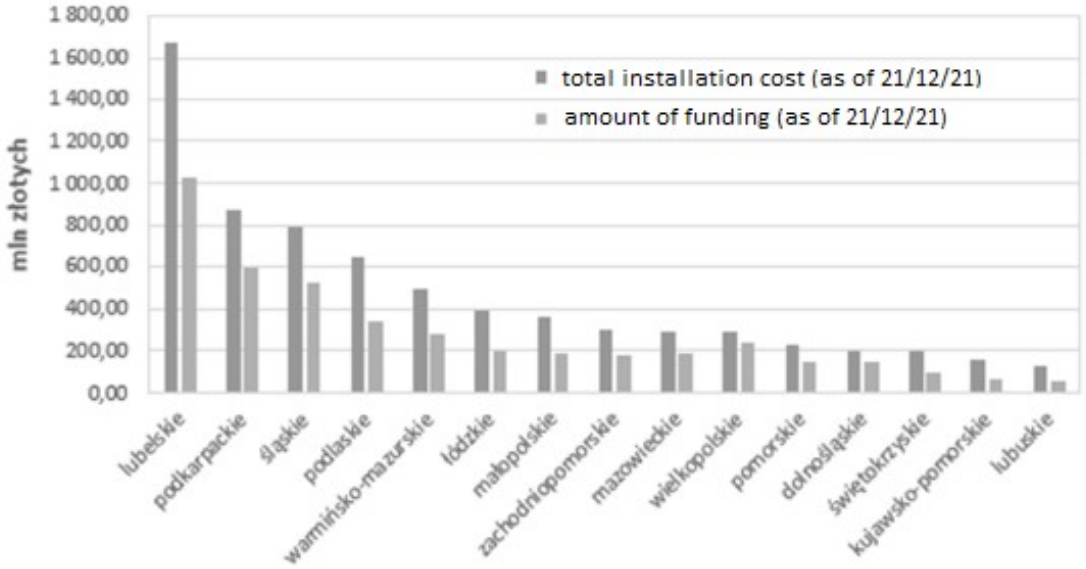

Figure 43. Financial resources obtained by Polish voivodeships for renewable energy under programs: European Regional Development Fund and Operational Program Infrastructure and Environment Sources. Source: (Przygodzka et al., 2023)

7. CONCLUSIONS

Ultimately, this report is a preliminary exercise for informing the initial start up of the VALUE4FARM project. The collected information focuses on general policy information and does not reflect a comprehensive overview of the policy landscape relevant to sustainable agriculture and renewable energy. Detailed and thorough policy analysis will be conducted iteratively as part of WP4, where this report will be used a foundational basis for informing stakeholder surveys, expert interviews, and further literature review on relevant policy areas such as research and development, industry, waste, environment, biodiversity, climate, etc.

The conducted literature review provides helpful insights into understanding the policy landscape surrounding agrivoltaics and biogas/biomethane production in the EU. In regard to demonstration sites under investigation within the VALUE4FARM project, the influence of policies should be understood at the level of individual stages in the biomass value chains, i.e., biomass production, inbound and outbound logistics, processing and production of biofuels, and ultimately the end uses resulting from the value chain. Furthermore, it is also helpful to examine the broad policy landscape surrounding agrivoltaic and biogas/biomethane value chains, which this report defines as the bioeconomy, renewable energy, socio-economic, and environmental systems and the policies that define their conditions. The most relevant policy tools for promoting the uptake of agrivoltaic and biogas/biomethane systems include first and

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foremost regulatory and economic (hard) instruments, with voluntary action, informational, market-based signaling, and visionary (soft) instruments also being useful tools for enacting change. In regard to financially supporting renewable energy sources, FiTs, FiPs, net metering, and tender schemes are identified as key policy tools.

An overview of the state of the EU agriculture and renewable energy markets, as well as the development and challenges of agrivoltaics and biogas/biomethane in Europe is provided in the following points.

- EU agriculture holds a dominant position in the overall EU bioeconomy. It is defined by a shrinking workforce, growing economic output, higher employment levels in many eastern and southern regions, and underdeveloped potential for renewable energy production.
- EU energy consumption is still largely dependent on foreign fossil fuel imports to meet approximately half of its energy demands. Nevertheless, renewable energy production and consumption is steadily rising and the current energy crisis has motivated the EU to create the EGD-aligned REPowerEU Plan promoting more renewables and energy independence.
- Agrivoltaics is an underdeveloped industry in the EU with an enormously projected potential for increasing EU solar energy capacities, i.e., using 1% of EU UAA is projected to create nearly 1 TW of energy. Furthermore, the high energy yield of agrivoltaics (2400 GJ/ha) far exceeds yields produced by biofuel crops (between 30 to 100 GJ/ha), which reinforces the increased energy production potential proposed in the VALUE4FARM model value chain combining both agrivoltaic solar energy production and biogas/biomethane production from biomass crop residues.
- The main challenge for agrivoltaics is the lack of an EU-standardised definition, which currently places farmers with agrivoltaic installations at risk for new land designations that would restrict their access to agricultural subsidies. In order to remedy this, EU member states must ensure that agrivoltaic installations do not change land designations for agricultural subsidies outlined in national CAP Strategic Plans.
- Biogas and biomethane production in the EU have steadily risen over the past decade, with current trends and future projections showing biogas levels stagnating and biomethane growing rapidly. The shift in focus from biogas to biomethane will expand the utility of renewable gas production, allowing for the increased replacement of natural gas with biomethane in transport, industry, power, and heating. Nevertheless, the market transition faces many challenges, the most prominent being that current biomethane production methods are still largely reliant on government support mechanisms and need to continue to transition away from energy crops to biomass residues. Further R&D and technological improvements are necessary for efficient and cost-effective biomethane production methods.

Key takeaways regarding the EU policy landscape are outlined in the following points.

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- Under the umbrella of the European Green Deal, there is an extensive framework of policy strategies outlining plans to update European legislation in order to transition the EU to become climate neutral by 2050. In regard to the policy areas of agriculture, renewable energy, agrivoltaics, and biogas/biomethane, the most relevant policy plans respectfully include:
    - EU CAP, which defines a framework for member states to develop national CAP Strategic Plans that must incorporate EU-defined environmental and climate standards to receive subsidies for farmers and rural development;
    - RePowerEU Plan, which outlines the actions and investments needed in energy infrastructure and technological innovation in order to accelerate the transition to renewable energy sources;
    - Biomethane Action Plan, which aims to incentivise the expanded use of biomethane through the Biomethane Industrial Partnership, as well as guide national member states biomethane strategies through EU goals like reaching 35 billion m^3 (350 TWh) in biomethane production by 2030.
    - Solar Energy Strategy, which defines the necessary steps, i.e., streamlining permitting processes, integrating PV generation into all sectors, and financing PV projects, to reach the target of increasing PV capacity in the EU to over 320 GW of solar PV by 2025 and almost 600 GW by 2030.
- In connection with enacting EU policy plans, the regulatory framework within the EU involves a wide array of tools and binding targets, which define how national legislation within member states must and can support sustainable agriculture and renewable energy. Furthermore, the recent Fit for 55 legislative package has pushed another wave of ambitious directives and regulations that will define the trajectory of upcoming policy and legislation within member states. In regard to the VALUE4FARM project, prominent legislation outlines the following mandates which will influence how EU members states will regulate and promote agrivoltaics, biogas, and biomethane:
    - renewable energy consumption in the EU must reach 42.5% by 2030;
    - solar energy capacity must reach 710 GW by 2030;
    - new biofuel plants must produce at least 65% fewer direct GHG emissions than fossil fuel alternatives;
    - new biomass-based heat and power plants must produce at least 70% (80% in 2026) fewer GHG emissions than fossil fuel alternatives;
    - large-scale bioelectricity plants, i.e., above 50 MW, must either apply highly efficient cogeneration technology, apply best available techniques (BAT), achieve 36% efficiency (for plants above 100 MW), or use carbon capture and storage technology;
    - new energy tax rates categorise electricity and heat from fossil fuels to more expensive, making renewable energy sources like PV and biomethane indirectly more competitive;
    - new national targets to reduce emissions of ESR sectors by 40% compared to 2005, which is also paired with a new emissions trading system (ETS 2);
    - organic waste must be collected separately by 2024, offering an opportunity to scale-up the production of sustainable biogas and biomethane and create income opportunities for farmers and foresters.

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Notably, tensions can often exist between policy plans and available regulatory instruments. Plans like the EGD promote ambitious and challenging visions for sustainable economies and renewable energy transitions, and EU-level policy frameworks are often limited in their ability to leverage action. Therefore, it is important to understand how policies and regulations are enacted from EU to national levels, as well as the status quo of national policy landscapes. Key takeaways regarding the agriculture and renewable energy policy landscapes within Denmark, Belgium, Italy, and Poland are provided in the following subsections.

Denmark

Denmark's national target is to reach 100% renewable power supply by 2030 and biogas/biomethane is one important pillar to achieve that. The NECP puts special emphasis on renewable energies and bioenergy from biogas and biofuels. Biomass for heating is promoted with tax relieves. At the moment, renewable energy already accounts for 45% of the energy system with wind energy being dominant in the electricity sector.

The energy use in agriculture dropped significantly by 25% since 1990. Regarding agrivoltaics, no explicit regulations exist but conventional PV systems are supported on agricultural land if it remains cultivated or its condition is maintained. Subsidies of bio-schemes for biodiversity and sustainability are no longer payed for areas beneath the solar panels.

Biogas plays a central role in Denmark since 1970 and there are many large scale and centralized plants. Most of them already upgrade biogas and lead it into the grid, so that around 40% of all gas originates from biomass. Biomethane production with the methanation of CO_2 is still in an early stage on the demonstration size. So far, only a support scheme for upgrading biogas is in place but a subsidy scheme for the sale of valorised CO_2 to methane is in development.

The development of biorefineries in Denmark took off in 2013 with the need for perennial crops and to comply with the EU Water Framework. The agreement on the green transition of the agricultural sector supports the plant-based food sector as biorefining of grass for protein. There are two commercial biorefinery facilities. Restrictions on the use of energy crops for biogas pushed the development for biorefineries since the press cake fibres from it can be used instead.

Belgium

Agriculture in Belgium is not as extensive as in other EU countries like Italy, but it still holds a potential for biogas/biomethane production as well as for agrivoltaics, which is at the moment is only implemented at the pilot level due to missing regulatory support. Due to the phase-out of nuclear power, which is contributing 50% to the electricity mix, there is a need to implement more renewable alternatives to avoid fossil fuel dependency.

In Belgium the energy and climate policies are divided between the federal and regional governments. Therefore, regional policies are an important driver for renewable energy development since they provide

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clear and partly more ambitious targets then the national energy and climate policy, which will undergo an update in 2024. The Flemish Energy and Climate Agency monitors GHG emissions in Flanders with regular reporting and public consultation with stakeholders. All over Belgium, there exist support schemes for biogas plants, with subsidies via certificates or for investments. Digestate can be applied as fertilizer on the fields following good practices and considering the fertilisation regulations.

Italy

Italy, with the second biggest biogas market in Europe, has a 30 years old history of subsidies for biogas. Bureaucratic hurdles to receive FiTs were removed for small scale biogas plants and restrictions for the use of by-products was simplified as a reaction to the energy crisis stemming from the war in Ukraine. Since 2023, the newest development favours the processing of biogas into biomethane. One driver for this is the possible usage in natural gas vehicles, which are common in Italy, and the extension of the natural gas grid. It is supported by investments in new or converted plants as well as with CICs, which can be sold to fuel suppliers for the amount of energy supplied as biomethane.

Regarding agrivoltaics, new developments started in 2023 with implementation in the national RRP. It includes a framework with the requested characteristics and requirements as well as simplified procedures for the construction of facilities.

Poland

The bioeconomy, with established agri-food, forestry, and chemical industries, is a highly important sector of the economy in Poland. The country has the fifth biggest agricultural production in Europe, which sets a strong basis for primary and secondary sectors like the pharmaceutical industry.

Due to the fragmentation of agricultural production, especially smaller biogas plants exist, which are supported by a variety of policies like subsidies for investments, CoO, PPA, FiTs, etc. With the Special Biogas Act, the use of digestate as fertilizer was facilitated if it meets environmental requirements. There is not yet a biomethane market and only some facilities in development. While the rooftop solar market is the fastest growing in Europe, agrivoltaic installations are not yet implemented in Poland, because the regulatory framework does not allow a dual land use.

The region Lublin, as a highly productive agricultural area, has a high potential for biogas/biomethane from agricultural waste. Cooperation from several clusters, which are settled in the region, can potentially drive that development. Renewable energies are supported with a regional development strategy, which aims to improve the energy efficiency of farms and increase their renewable energy production, as well as with several funds like the European Regional Development Fund and Operational Program Infrastructure and Environment.

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8. ANNEXES

ANNEX I - LITERATURE REVIEW GUIDELINE TEMPLATE

Date	Date the sheet is filled
Country	Partner's country
Partner(s)	Name of person(s) responsible for filling this sheet and corresponding institution

Table 3. Partner information collection table

Please note:

- The following sections will serve as sub-chapters for Deliverable 1.3. The expected length of the completed template is 5-10 pages for each country (with 3-5 pages of written content). Therefore, it is encouraged to use diagrams, informative figures and tables, which can be used in the final deliverable.
- It is recommended that partners download this template and use it to structure their respective national and regional regulation framework analyses.
- The regulation framework analysis is meant to inform the protocols developed in WP2. Therefore, use your contribution to the regulation framework analysis as an opportunity to collect policy information that will inform the development of the WP2 protocols and their implementation in your respective country.

[COUNTRY]'S BIOECONOMY AND RENEWABLE ENERGY POLICY LANDSCAPE

Please note: This literature review aims to provide a relatively comprehensive overview of the country's bioeconomy and renewable energy market and policy landscape. However, due to time constraints of the T1.3, please prioritize providing insights into the VALUE4FARM technologies and value chains most relevant to your country.

Overview of the National Bioeconomy and Renewable Energy Market

Before directly discussing policies in each country, it is important to provide context information including the framework in which bioeconomy, renewable energy, and VALUE4FARM technologies and value chains are implemented.

Please use the following points to guide this section:

- Bioeconomy and renewable energy market size (in monetary terms or significance to the country's economy)

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- Development stage of the bioeconomy and renewable energy in the country (a developed sector is characterized by a significant market share, high innovation levels and distribution of novel technologies as well as judicial instruments and inter-connectivjty of stakeholders)
- Evolution of past development and current discussion and trends
- Prominent sectors and value chains
- Development status of VALUE4FARM technologies and value chains

Overview of National Bioeconomy and Renewable Energy Policies

This section aims to provide a snapshot of the current situation in each of the countries regarding national bioeconomy and renewable energy policies to facilitate market development and technology implementation.

Please note: The following policy instruments are relevant for consideration within this literature review:

1. Direct regulation / regulatory (binding) instruments
   - E.g., quotas, targets, product standards, permitting instruments, etc.
2. Economic/financial instruments
   - E.g., subsidies, loans, tradable certificates, tax incentives, research and innovation funds, etc.
3. Voluntary initiatives
   - E.g., codes of good practice, self-regulation, non-obligatory financial incentives, networks, etc.
4. Information and advisory instruments
   - E.g., education or awareness programs
5. Market-based signaling instruments
   - E.g., information provisions like labels, traceability, and voluntary certification schemes
6. Other instruments such as vision documents, road maps, strategies
   - E.g., guideline documents

Please use the following points to guide this section:

- Implementation of European law (how EU directives and regulations are manifested in national law?)
- National bioeconomy and renewable energy strategy goals and key policies (if there are no bioeconomy or renewable energy-specific strategies, please include mentions of other relevant national strategies)
- Other bioeconomy and renewable energy-related policies (e.g., usually, many regulations are shaping the bioeconomy or renewable energy even though they do not explicitly deal with the either. For example, those related to waste, energy, construction, or climate change)
- National policies related to the VALUE4FARM technologies and value chains

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Overview of Regional Policies

In this section, the goal is to zoom into the regional level of the demonstration and replication sites and highlight regional policy mechanisms which relate to (1) the bioeconomy and renewable energy and (2) the specific value chains and technologies in VALUE4FARM. Countries may vary in the level of legislative activity on the regional level (e.g., some countries practice more centralized governance while others allow more agency in states, districts or municipalities). Therefore, first describe how policies are realized locally, then describe the specifics of the policy mechanisms.

Please indicate the following points and specify:

- Local strategies for bioeconomy and renewable energy
- Regional regulations affecting bioeconomy and renewable energy
- Any networking initiatives (clusters)
- Funding/investment projects
- Research activities, knowledge transfer, demonstration projects

SOURCES

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ANNEX II - LIST OF IDENTIFIED POLICY INSTRUMENTS

The organisation of relevant polices involves mapping their position in the VALUE4FARM policy landscape. So far, this task has been completed with Italian biogas/biomethane policies. Further mapping of EU, Danish, Belgian, Polish, and Icelandic policies will occur in Task 4.4.

Territory	Year	Policy Name	Government Level	Instrument Type	Focus in Policy Landscape	Description of Policy Aims
IT	2014	il decreto del MiSE del 10 ottobre 2014 e ss.mm.ii	National	BM - Ministerial Decree (Regulatory)	• Bioeconomy and Renewable Energy Systems	The decree defines the conditions, criteria, and methods for implementing the obligations to use renewable energy sources in the transport sector.
IT	2015	Deliberazione 210/2015/R/gas e ss.mm.ii	National	BM - Resolution (Regulatory)	• Outbound Logistics	The resolution defines the directives regarding market processes relating to the introduction of biomethane into natural gas transport and distribution networks.
IT	2016	Decreto interministeriale 23 giugno 2016	National	BG - Interministerial Decree (Regulatory)	• Socio-economic, Bioeconomy, and Renewable Energy Systems	The decree regulates the incentives for renewable sources other than photovoltaic for new plants selected in 2016. The incentive period will last twenty years (twenty-five for thermodynamic solar). The new incentives are paid in compliance with the overall ceiling of €5.8 billion per year for renewable energy, other than photovoltaic, currently in the bill. The incentives are assigned through reverse auction procedures differentiated by technology for large plants (>5 MW), while plants below this threshold must request registration in specific registers.

IT	2016	DM 5046 25/02/2016	National	BM - Ministerial Decree (Regulatory	• Environmental Systems • Biomass Production / Supply • End Use	The decree defines indicators related to the spreading of manure and digestate. In the case of agricultural plants located in areas vulnerable to nitrates with a nitrogen load of zootechnical origin exceeding 120 kg/ha, as defined by the regional action plans, the use of at least 40% by weight of zootechnical effluents in the overall authorized power plan.
IT	2018	DM 2/3/2018	National	BM - Ministerial Decree (Regulatory	• Bioeconomy and Renewable Energy Systems • Outbound Logistics • End Use	The decree encourages advanced biomethane by providing its sole destination for consumption for transport.
IT	2018	La Legge n. 145/2018	National	BG – Law (Regulatory)	• Socio-economic, Bioeconomy, and Renewable Energy Systems	The law extends the possibility of access to incentives, according to the procedures, methods, and tariffs of the Ministerial Decree 23/06/2016, to "electricity production systems powered by biogas, with electrical power not exceeding 300 kW. Systems must form part of the production cycle of an agricultural or livestock enterprise, be created by agricultural entrepreneur(s), and be fueled by at least 80% manure and materials deriving from the agricultural companies and 20% from their second harvest crops".
IT	2019	DM 14/11/2019	National	BM - Ministerial Decree (Market-based Signaling)	• Bioeconomy and Renewable Energy Systems	The decree establishes the national certification system for the sustainability of biofuels and bioliquids.

IT	2020	norma UNI TS 11567	National	BM - Technical Standard (Market-based Signaling)	• Bioeconomy and Renewable Energy Systems	The technical standards contain the guidelines for the qualification of economic operators in the biomethane production chain, for the purposes of traceability and the mass balance system. The document defines a qualification scheme for organizations operating in the biomethane production chains obtained in a sustainable manner.
IT	2020	Deliberazione 64/2020/R/gas e ss.mm.ii	National	BM – Resolution (Regulatory)	• Outbound Logistics	The resolution establishes the directives for the connections of biomethane plants to natural gas networks and provides provisions regarding the determination of the quantities of biomethane eligible for incentives.
IT	2021	D.lgs. n. 28/2011/2021 e D.lgs. n. 199/2021 e D.lgs. n. 387/2003	National	BM – Law Decree (Regulatory)	• Bioeconomy and Renewable Energy Systems	The decree defines the regulations relating to the authorization/license for the construction or reconversion of plant.
IT	2021	La legge 26 febbraio 2021, n. 21	National	BG – Law (Regulatory)	• Socio-economic, Bioeconomy, and Renewable Energy Systems	This law extends the incentives, introduced by the 2019 budget law, for biogas-powered plants with electrical power not exceeding 300 kW to the end of 2021 and within the limit of a further annual cost of €25 million. These systems, in addition to the requirement of electrical power, must form part of the production cycle of an agricultural or livestock enterprise, be created by agricultural entrepreneur(s), and be fueled by at least 80% manure and materials deriving from the agricultural companies and 20% from their second harvest crops.
IT	2021	decreto legislativo 8 novembre 2021 n. 199	National	BG- Law Decree	• Bioeconomy and Renewable	The decree defines the tools, mechanisms, incentives, and institutional, financial, and legal framework necessary to achieve the

				(Regulatory, Market-based Signaling)	Energy Systems	objectives of increasing the share of energy from renewable sources by 2030, in implementation of Directive (EU) 2018/2001. The decree contains provisions necessary for the implementation of the measures of the RRP regarding energy from renewable sources, with the aim of identifying a set of coordinated measures and tools, with which the EU is expected to have a binding target of reducing GHG emissions by at least 55% compared to 1990 levels by 2030.
IT	2022	DM 15/9/2022	National	BM - Ministerial Decree (Economic / Finanical)	• Socio-economic, Bioeconomy, and Renewable Energy Systems • Outbound Logistics • End Use	The decree promotes biomethane injection into the natural gas network through a capital account support (equal to a maximum of 40% of the expenses incurred) and an energy account incentive (incentive tariff applied to the net production of biomethane).
IT	2022	legge n.15 del 25 febbraio 2022	National	BG- Law (Economic / Finanical)	• Socio-economic, Bioeconomy, and Renewable Energy Systems	The decree provides the extension to 2022 of incentives for electricity production plants powered by biogas, with electrical power not exceeding 300 kW.
IT	2022	decreto-legge 21 marzo 2022, n. 21	National	BG - Law Decree (Regulatory)	• Bioeconomy and Renewable Energy Systems	The decree lists urgent measures to increase the production of electricity from biogas. Full use of the installed technical capacity for the production of electricity from biogas coming from plants already in operation is permitted through additional production compared to the nominal power of the plant, within the limits the

						technical capacity of the systems and the technical capacity of the connection to the grid, and in compliance with current legislation on environmental impact assessment and integrated environmental authorisation.
IT	2022	IL DECRETO-LEGGE N. 17 DEL 2022: “DECRETO ENERGIA”	National	BG - Law Decree (Regulatory)	• Biomass Production / Supply • Processing and Conversion	The law describes the use of by-products in biogas and biomethane plants (art. 12-bis). It is proposed to admit in biogas and biomethane production plants by-products coming from agricultural and livestock activities, the management of greenery and forestry activities, and food and agro-industrial activities envisaged by the ministerial decree of 23 June 2016.
IT	2023	La legge di conversione, n. 95 del 26 luglio 2023	National	BG (Regulatory, Economic / Financial)	• Bioeconomy and Renewable Energy Systems	The law establishes various measures regarding the production of energy from plants powered by biogas and biomass, urgent measures to increase the production of biomethane, as well as the use of alternative energy products, interventions to support the production of electricity from renewable sources, as well as measures urgent to contain the effects of price increases in the electricity and natural gas sectors. With regard to plants powered by biogas and biomass and the production of biomethane, a system of guaranteed minimum prices is defined. The minimum guaranteed prices, or revenue additions, are paid to cover operating costs, in order to ensure the continuation of the operation and efficient operation of the plant. The minimum guaranteed prices, i.e., the revenue additions, are differentiated based on the power of the system.