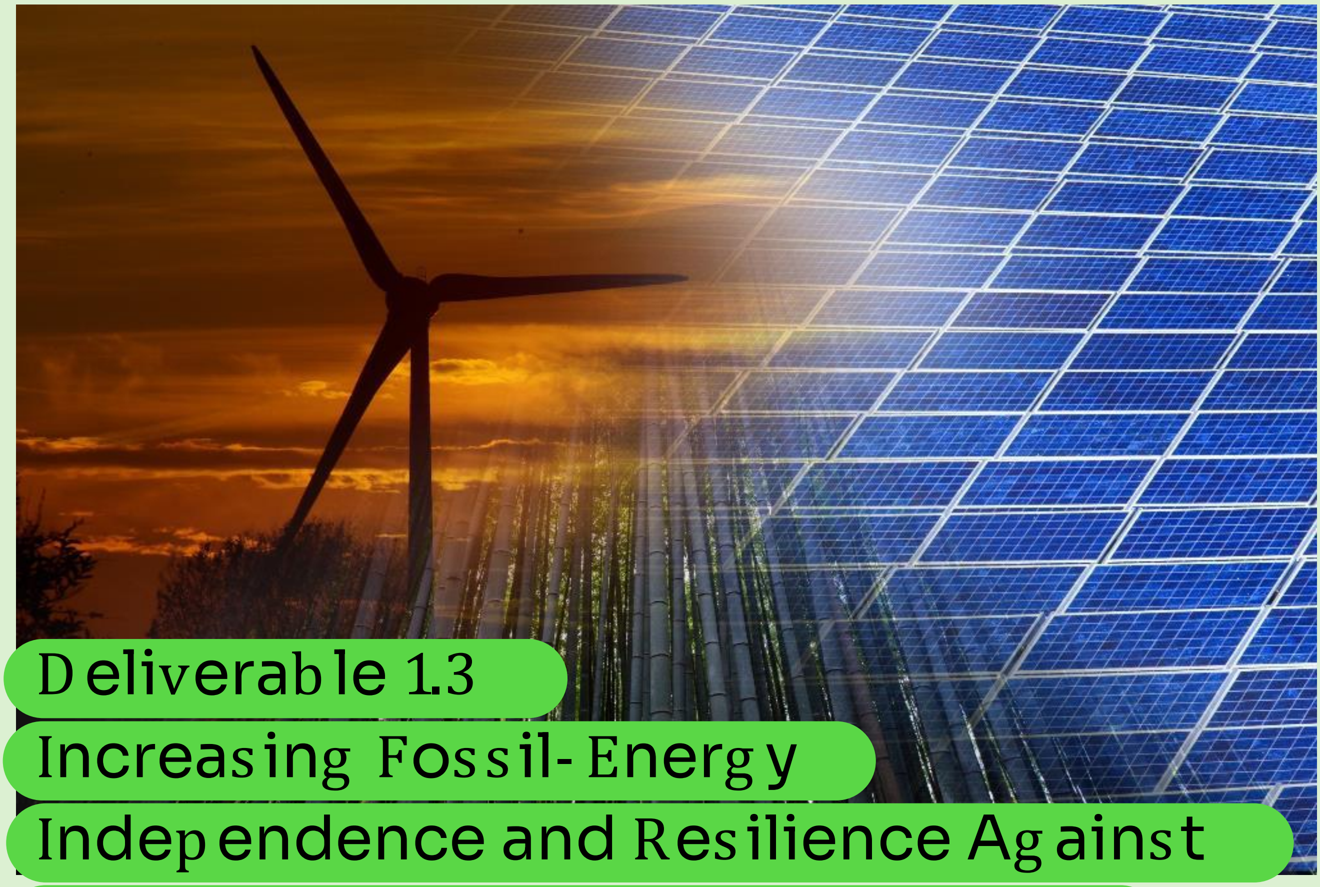
AgEnRes



Deliverable 1.3
Increasing Fossil-Energy Independence and Resilience Against Input Price Fluctuations: Selected indicators and data & modelling requirements

Project acronym: AgEnRes

Project title: Analysing of Fossil-Energy Dependence in Agriculture to Increase Resilience against Input Price Fluctuations

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Executive Summary

While contributing around 1.3% of the EU's GDP (EC, 2021), agriculture is responsible for about 10% of the EU's total greenhouse gas emissions (EC, 2023b), a significant portion of which comes from fossil fuel use for machinery, transport, and fertilizers (EC, 2023a). This reliance not only conflicts with the EU's goal of achieving climate neutrality by 2050, but also exposes the sector to significant economic risks seeing the high volatility of fossil fuel and fertilizer prices in the context of Russia's invasion of Ukraine. Shifting to energy-efficient, low-carbon practices is not only climate effective, but also economically viable.

Drawing on the idea of the interconnectedness of the agriculture and energy systems at the **agri-energy nexus,** the AgEnRes project addresses the urgent challenge of reducing fossil fuel dependence and enhancing energy resilience in European agriculture. Following earlier deliverables analysing the policy environment (D1.1) and technological innovation in different regions of Europe (D.1.2), this report provides the groundwork for a shared terminological and conceptual basis for developing a set of comprehensive indicators for the further analytical work in AgEnRes on reduced fossil-energy use, renewable energy adoption, and efficiency improvements in farming systems. Different data requirements exist for assessing i) energy dependence, ii) energy saving technologies as well as iii) the adoption potential of innovation. Correspondingly, this review report elaborates on approaches at the agri-energy nexus relevant for both science and policy for monitoring and assessing policy measures that address energy use, energy efficiency or fluctuation of energy-intensive inputs in agriculture, by:

1. Reviewing CAP result indicators for relevance to energy efficiency and emissions reduction in agriculture and their compatibility with AgEnRes research objectives and data requirements.
2. Identifying pertaining gaps in research and practice as to where additional indicators are needed to better assess the transition to a low-carbon and energy-resilient approach to agriculture.
3. Defining key principles and requirements for policy evaluation indicators across environmental, social, economic, and governance dimensions at the agri-energy nexus.

Review approach

This deliverable was developed in close collaboration with consortium partners and stakeholders from policy and practice. Building on key findings from previous tasks, several review steps were taken to build the analytical basis for the project's further exploratory work.

In a **first review** step pre-selected **CAP result indicators** identified in D1.2 were screened organized along three distinct sub-steps:

1. Reviewing project tasks and data needs based on the grant agreement
2. Internal review and feedback on CAP indicators
3. Validation by key experts in the consortium regarding
    a. Data & model requirements
    b. Feasibility and relevance of indicators

The **second review** step approached indicators for policy evaluation from a **scientific perspective**. Employing innovative AI based review techniques (AS Review) literature was searched for suitable indicators from a broad range of articles focused on energy use in agricultural activities, including crop production, glasshouse operations, animal husbandry, or fertilization.

Based on a long list of policy indicators consortium partners and key stakeholders discussed the:

1) Quality of existing indicators specifying the requirements for evaluating specific indicators as 'good'; as well as
2) Pertaining challenges and gaps considering the research needs of subsequent work packages

Third, a **discussion** was held with **stakeholders** from science, policy and practice as to refine the list of indicators for policy evaluation at the agriculture-energy nexus on the basis of insights from the literature review. This second workshop was designed around two major objectives:

(a) Defining goals for policy indicators to specifying principles and justification for assessing indicators as 'good'
(b) Evaluating key indicators from literature based on conceptual considerations of quality or functionality; making explicit concrete features or metrics that make indicators practically useful, while exploring pertaining limitations, gaps or trade-offs.

Key insights

The work in the AgEnRes project (re)affirmed the importance of a flexible and comprehensive indicator framework at the agri-energy nexus. Such framework combines a mix of simple, high-level indicators—such as the share of farms using renewable energy—with more detailed metrics, like energy efficiency per hectare. Combining simplicity with depth ensures the indicators are both actionable for policymakers and reflective of the complexities of agricultural energy dynamics.

CAP result indicators

CAP indicators on risk management, farm modernization, renewable energy, climate investments, sustainable nutrient management, or organic agriculture were found to be principally highly relevant but also required better measurement methods. Eventually, however, none of the reviewed CAP result indicators received a fully positive assessment, mostly because metrics in use are too basic, such as the number of farms or areas benefiting from CAP funding. Such metrics are insufficient for tracking trends or actual policy impacts.

Indicators based on relative values, like the share of utilized agricultural area (UAA) receiving payments would be more insightful. Indicators concerning knowledge transfer, innovation, or risk management tools, although principally relevant are too generic in monitoring practice as to allow understanding specific services or innovations and their corresponding quality or impact on energy dependence.

This mismatch with analytical requirements in AgEnRes reaffirms Deliverable 1.1 insights that existing policies and support measures – including their approaches to monitoring – do not reflect well the relevant considerations at the energy-agriculture nexus. While the indicators are generally relevant, they need considerable adjustment and refinement to improve precision and adaptability for assessing sustainable agricultural practices reflecting progress towards independence from fossil-energy inputs and price volatility.

Indicators in scientific literature

A total of 175 unique indicators were extracted from 45 included studies, with individual studies often containing multiple indicators. Apart from individual country contributions, EU-wide studies represent a significant portion of the research, spanning multiple countries and assessing EU level policies, accordingly. Overall, the list of indicators is quite comprehensive on the environmental and economic dimension. However, there is a clear dominance of indicators measuring environmental aspects, especially concerning nutrient pollution and to a lesser extend also greenhouse gas emissions or soil.

Economic topics, like farmer income, are addressed frequently, however, only a limited number of indicators are specifically targeted at energy use and related dependency of the agricultural sector. Only one indicator captures risk attitudes of farmers, which is a central aspect of AgEnRes. Beyond that, the social and governance aspects are poorly represented and "mixed" indicators that measure a combination of aspects from all four sustainability categories mostly combine only the environmental and economic metrics. The Indicator Dataset is publicly available here.

Stakeholder evaluation

Environmental indicators were generally evaluated as providing solid grounds for practical purposes in science and policy to track policy impacts. However, numerous are difficult to apply universally or require more accuracy to be effective (esp. GHG or nitrogen surplus).

Indicators measuring the performance on the economic dimension were seen key for assessing the impact of policies on farmer's wellbeing. While existing indicators, like fertiliser expenditure per hectare, already offer insights into actual costs of an important fossil-energy based input, more indicators were needed to measure the marginal abatement cost related to expenses of reducing environmental harm, although complex and difficult to interpret. In this respect, general concerns arose about fair sharing of costs between farmers and society.

The singular social indicators, farmers' willingness to adopt energy-saving technologies, evoked high interest, but was seen as limited in that willingness does not always translate into action. Indicators need to better reflect actual achievements through new policies and help elaborate on the behavioral drivers of adopting innovation to support policy making.

On governance, a dimension absent in the literature, stakeholders favour indicators that ensure transparency and accountability in democratic policymaking processes, including to being able to assess administrative burden imposed by (new) policies on institutions and beneficiaries.

There was a particularly high interest in mixed indicators combining economic, environmental, and social factors. Eco-efficiency as indicator was deemed outstanding principally allowing to outbalance sustainability considerations with aspects of economic performance. Hidden assumptions were seen to make interpretation and application hard in practice, though. By contrast, possible bias in many mixed approaches prioritising economic over other aspects of sustainability were not thematised.

Discussion and conclusion

Although numerous of the existing CAP policy result indicators were relevant for AgEnRes - like renewable energy or climate innovations, or sustainable nutrient management, metrics are typically not tailored to the specific policy objectives at the agri-energy nexus for tracking progress towards fossil energy independence or resilience. Indicators may have to be adapted, being more explicit about:

- Specific energy saving technologies
- Knowledge or management approaches applied
- Exact costs incurred by innovations
- Area/UAA instead of number of farms

Furthermore, they need to address the pertaining gap in CAP indicators concerning the governance function allowing to reflect on the democratic quality of policy measures more generally, including through sharing openly what public money is spent for exactly.

The literature review and stakeholder exchange supported the notion that for analysis specific to the agri-energy nexus indicators are needed that focus more specifically on exact sources of nutrients or emissions to trace their fossil energy source and/or reliance on imports, accordingly. Targeted decision making relies on more nuanced information. This also holds for economic indicators. While expenditure on energy and fertilisers in combination with total farm income already indicate dependency on (fossil) energy inputs well, the picture becomes clearer where production efficiency is assessed in terms of, e.g., energy costs per unit of product sold. Considering the implications of fossil fuel price fluctuations for the resilience of a business in the agricultural sector, decisions under risk deserve more attention in theory and policy including behavioural dynamics behind innovation. Against this backdrop, also the factors and behavioural drivers behind adoption of innovation deserve higher consideration. Overall, energy dependence of agriculture is still not a core aspect of current interest when designing indicators to assess sustainability in agriculture, neither in policy, nor in academic discussion.

Gaps persist especially with mixed indicators (considering trade-offs, e.g. with biodiversity), whereas behavioural indicators (understanding better adoption and taking risks) are needed to make model predictions more accurate and in consequence also more salient to political decision making and planning. Governance and social indicators, although still very rare, score high on fairness or accountability principles in knowledge production and should be in the ‘self-interest’ of democratic policy-making.

In this regard, the AgEnRes project provides a first, relevant analytical foundation for developing energy-specific agricultural policies and indicators for Europe. By addressing pertaining gaps in current frameworks and proposing actionable solutions, this report provides a first stock-take of more effective monitoring of fossil fuel reliance, energy efficiency, and renewable energy adoption to be further specified in subsequent work packages.

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List of Acronyms/Abbreviations

AES	Agri-environment scheme
AI	Artificial Intelligence
CAP	Common Agricultural Policy
CO2	Carbon Dioxide
CSP	CAP Strategic Plans
D	Deliverable
EC	European Commission
EU	European Union
GHG	Greenhouse Gas
LU	Livestock Unit
PMEF	Performance Monitoring and Evaluation Framework
SOC	Soil Organic Carbon
UAA	Utilised Agricultural Area
WP	Work Package

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1. Introduction

While contributing around 1.3% of the EU's GDP (EC, 2021), agriculture is responsible for about 10% of the EU's total greenhouse gas emissions (EC, 2023b), a significant portion of which comes from fossil fuel use for machinery, transport, and fertilizers (EC, 2023a). This reliance not only conflicts with the EU's goal of achieving climate neutrality by 2050, but also exposes the sector to significant economic risks. The AgEnRes project addresses the urgent challenge of reducing energy consumption and dependency on fossil fuels in European agriculture.

A key factor driving this urgency is the volatility of fossil fuel and fertilizer prices, particularly since Russia's invasion of Ukraine in 2022, which triggered supply chain disruptions and sharp price increases (Colgan et al., 2023). Price volatility adds considerable insecurity to operating costs of farmers, jeopardizing the economic sustainability of farms across the EU. By reducing reliance on these inputs, the agricultural sector can enhance its resilience to market fluctuations, paving the way for more stable, long-term growth. This makes the shift to energy-efficient, low-carbon practices not only climate effective, but also economical.

The concept of the **agri-energy nexus** captures this interconnected relationship between agriculture and energy systems. It underscores how these two sectors mutually influence, depend on, and impact one another. Specifically, it examines the intersection of energy production and agricultural activities, emphasizing the energy required for farming operations and the role of agriculture in energy generation. The project is structured into several work packages (WPs) to systematically address the mentioned challenges. Work Package 1 (WP1) provides a shared and empirically substantiated analytical framework for the entire project by reviewing current approaches as well as potential improvements in energy use and efficiency in agricultural research, practice and policy. The framework takes stock and elaborates on the scope for further developing policy measures and targets, technologies as well as indicators in line with the overall project objective of increasing the resilience of farmers towards energy price volatility. In earlier deliverables from WP1, we made significant progress in laying this groundwork.

Deliverable 1.1 analysed the EU's existing policies on energy use in agriculture, identifying critical gaps to be addressed to better facilitate the sector's climate and energy transition. These policies include major frameworks such as the European Green Deal, but also specific agricultural support measures as those under the Common Agricultural Policy (CAP), as illustrated in Figure 1. The review found that specific policies targeting the agri-energy nexus are mostly absent. Currently, the EU policy landscape is marked by fragmented and partly conflicting set of different climate and agricultural strategies, directives and support measures making the achievement of a fossil-free agriculture in the EU both challenging and, in some cases, unlikely.

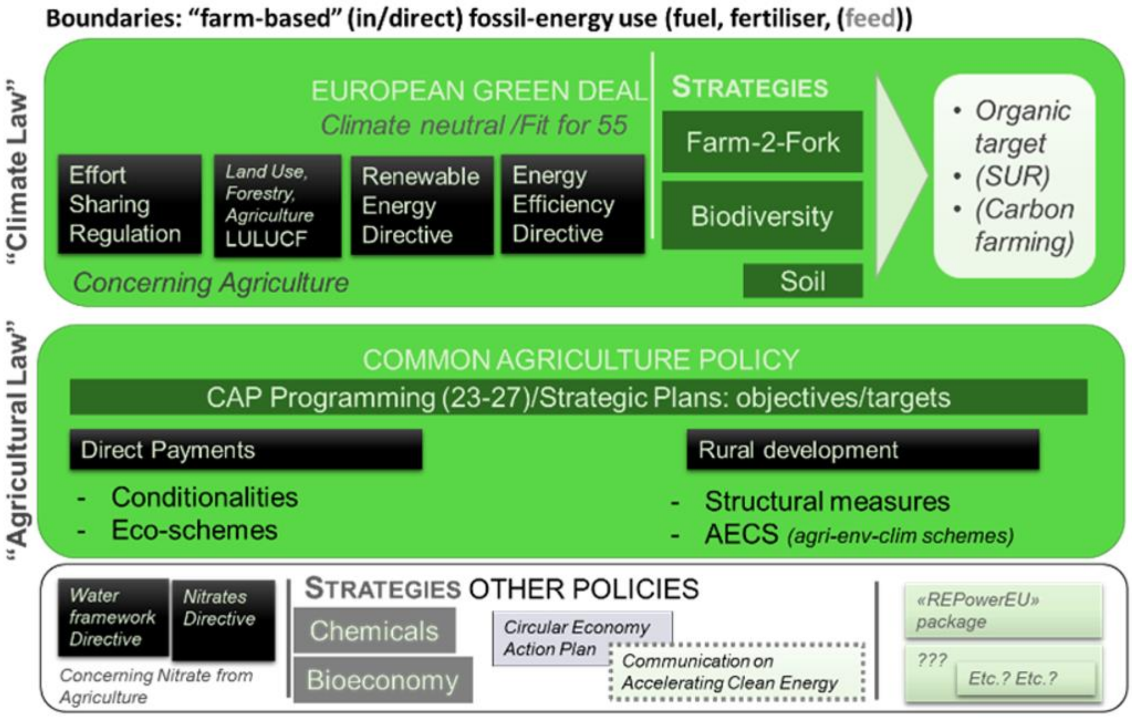

Figure 1 Overview of polices at EU level which target agriculture and energy use in a direct or indirect way (AgEnRes D1.1).

D1.2 explored innovations and technologies aimed at reducing energy consumption and emissions in agriculture, including precision farming, renewable energy integration (e.g., solar panels and biogas systems), and alternative low-carbon fertilizers. These advancements have the potential to cut fossil fuel use by as much as 40-50% in certain farming systems, particularly in energy-intensive processes such as tillage and drying. Figure 2 highlights some of the innovations discussed in D1.2.

Crop Production	• Reduced tillage • No-Tillage • Precision input application (VRF)
Animal Production	• Adjust feedings to needs & reduce feed loss • Low-temperature floor heating • Heat recovery system for milk cooling
Fertiliser Use	• Hydrogen /RE for ammonia production • alternative nutrient sources from waste • Fertilizer use efficiency: crop rotation
Renewable Energy	• Biogas • Photovoltaics & Agrovoltaics • Replacing heating devices - heat pumps

Figure 2 Examples for identified innovations to reduce fossil fuel and fertiliser use in EU agriculture. (AgEnRes D1.2)

Building on this foundation, the deliverable at hand expands the perspective in Deliverable 1.1 when discussing the existing EU CAP result indicators in terms of their alignment with the objective of reducing energy dependence and enhancing sustainability in EU agriculture. While the CAP plays a pivotal role in shaping agricultural practices across the EU, the existing result indicators for measuring impact fall short in effectively tracking progress on energy use and emissions reduction on all relevant economic, social and environmental impact dimensions. Moreover, they are neither harmonised nor consistent with the data and indicators used in current models as a basis for policy assessments, while they too often do not fully cover or integrate fossil fuel or energy-intensive inputs in socio-economic analyses at various scales. In a collaborative effort with experts and stakeholders at the agri-energy nexus, D1.3 provides the analytical groundwork for identifying a set of indicators relevant to both science and policy for monitoring and assessing policy measures meant to address energy use, energy efficiency and fluctuations of energy-intensive inputs in agriculture.

Aim and Structure of Deliverable 1.3

WP1 identifies and refines a set of indicators to address policy targets related to energy use, energy efficiency, and fluctuations in energy-intensive inputs in agriculture. This includes existing and new indicators that provide insights at various levels, supporting the monitoring and evaluation of policy measures and global drivers. For ensuring high political or practical relevance of the analytical framework elaborated on in task 1.3 the rationale behind the review was broadly aligned with that of the current Common Agricultural Policy (CAP) indicator framework, which differentiates between:

- Context indicators,
- Output indicators,
- Result indicators (e.g., number of rural jobs created), and
- Impact indicators (e.g., reductions in GHG emissions).

In a complementary literature review, policy indicators could be identified that are commonly used in scientific research to be contrasted with the CAP indicators. Two stakeholder workshops were held to discuss and refine the review findings. One internal workshop targeted researchers and experts in the field of data analysis and modelling elaborating on specific model requirements and research interests including explicating pertaining data gaps. A complementary workshop included external stakeholders, including from the European Commission and Member States, as to capture practical perspectives and expectations on effective policy indicators but also to reflect on the diverse views on agriculture and energy dependence. Engaging stakeholders from science and practice allowed to gain a shared as well as nuanced understanding of the core principles and objectives behind effective policy evaluation and indicators, considering the specificities at the agri-energy nexus.

Generally, the report and framework departed from the CAP result indicator and their evaluation. As a first step, existing EU policy indicators to assess policy outcomes and impacts were analysed with experts to assess their ability to measure the effects of policy measures – both short- and long-term – on fossil energy dependence in EU agriculture. Both direct and indirect energy use measurements were considered. Partners reviewed the list of indicators that were deem of relevance at least in a broader indirect way regarding their suitability for policy evaluation in terms of data availability and feasibility in modelling. Considering the elaborated shortcomings and gaps, a systematic literature review was conducted as a second step using innovative AI review tools. The resulting list and typology were further refined during a stakeholder workshop by elaborating on and discussing core principles for effective indicators and applying them to a subset identified in the review.

At this early stage of the project and considering the diversity of research questions in need of further refinement, research partners emphasized the need and preference for analytical guidance on indicator selection. The reflection of specific shortcomings of the existing CAP for the own data analysis and modelling tasks allowed specifying the scientific requirement for policy evaluation. In a collaborative effort engaging stakeholders from diverse sectors, including policy and academia, a framework of common principles and indicators could be developed for policy evaluation in the agri-energy nexus, thus addressing two key concerns in policy and sustainability science: the *quality* of indicators and their role in making policies assessable in practically meaningful ways. Previous literature (de Olde et al., 2017; Schreefel et al., 2024) highlights key characteristics of agricultural indicators and offers categorization approaches, which this report incorporates.

In summary, this deliverable:

Provides the groundwork for shared terminology and concepts for developing a set of comprehensive indicators for the analytical work in AgEnRes on reduced fossil-energy use, renewable energy adoption, and efficiency improvements in farming systems. It does so by the following steps:

- Review the CAP's result indicators for relevance to energy efficiency and emissions reduction in agriculture and their compatibility with AgEnRes research objectives and data requirements.
- Identify gaps in research and practice where additional indicators are needed to better assess the transition to a low-carbon, energy-resilient approach to agriculture.
- Define key principles and requirements for policy evaluation indicators across environmental, social, economic, and governance dimensions in the agri-energy nexus.

2. Evaluation of CAP Result Indicators

2.1 Building on previous work: D1.1 and D1.2

This deliverable was developed in close collaboration with other WP partners. By synthesizing key findings from previous tasks, the reviews were built on a solid foundation, ensuring coherence with the established project narrative. This approach provides a clear framework to establish the analytical and terminological foundation for the project's further exploratory work.

Further development of the policy list from 1.1

D1.1 concentrated on policies of relevance for the agri-energy nexus. It also presented the EU CAP indicators as shared tool used in political practice to evaluate the performance of EU policies, namely the implementation of the Member States CAP Strategic Plans. These indicators, established by the EC as part of the Performance Monitoring and Evaluation Framework (PMEF) for the CAP 2023-2027, aim to "*help assess the performance of the CAP 2023-2027 and improve its efficiency*." Member States have planned their actions toward the 10 CAP-specific objectives for 2023-2027 in their Strategic Plans using these indicators (EC, 2024).

In a preliminary desk-based review, the authors identified the most relevant indicators from the 44 available in the list in terms of their capacity to assess policy performance in relation to fossil energy dependence. A priority list of indicators that address the topic either directly or indirectly was compiled based on the 'common ground' of independent lists of the four reviewers involved:

Direct:

- **Indicator R.9** Farm modernisation: Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency *(incl. energy)*

- **Indicator R.15** Renewable energy from agriculture and forestry and from other renewable sources: Supported investments in renewable energy production capacity, including bio based (in MW)

- **Indicator R.16** Investment related to climate: Share of farms benefitting from CAP investment support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterial

- **Indicator R.22** Sustainable Nutrient Management: Share of utilised agricultural area (UAA) under supported commitments related to improved nutrient management

Indirect:

- **Indicator R.1** Enhancing performance through knowledge and innovation: Interventions supporting provision of knowledge, innovation and exchange in agriculture and rural areas to enhance sustainability and resource efficiency of performance

- **Indicator R.19** Improving and protecting soils: Share of UAA under supported commitments beneficial for soil management to improve soil quality and biota (e.g. reduced tillage, crop rotation) – *(reducing fertiliser needs)*

- **Indicator R.21** protecting water quality: Share of UAA under supported commitments for the quality of water bodies - *(may improve nutrient management, reduce pesticide and fertiliser use)*

- **Indicator R. 29**: Development of organic agriculture: Share of UAA supported by CAP for organic agriculture, with split between maintenance and conversion

Boundaries and exclusion criteria from D1.2

The key terminological framework for the work was established in D1.2, which defined the relevant boundaries for the agri-energy nexus. To identify the most promising technologies, the main energy flows associated with their application were selected. Energy use was categorized into direct and indirect inputs, both of which drive the agricultural sector, as illustrated in **Fout! Verwijzingsbron niet gevonden.**.

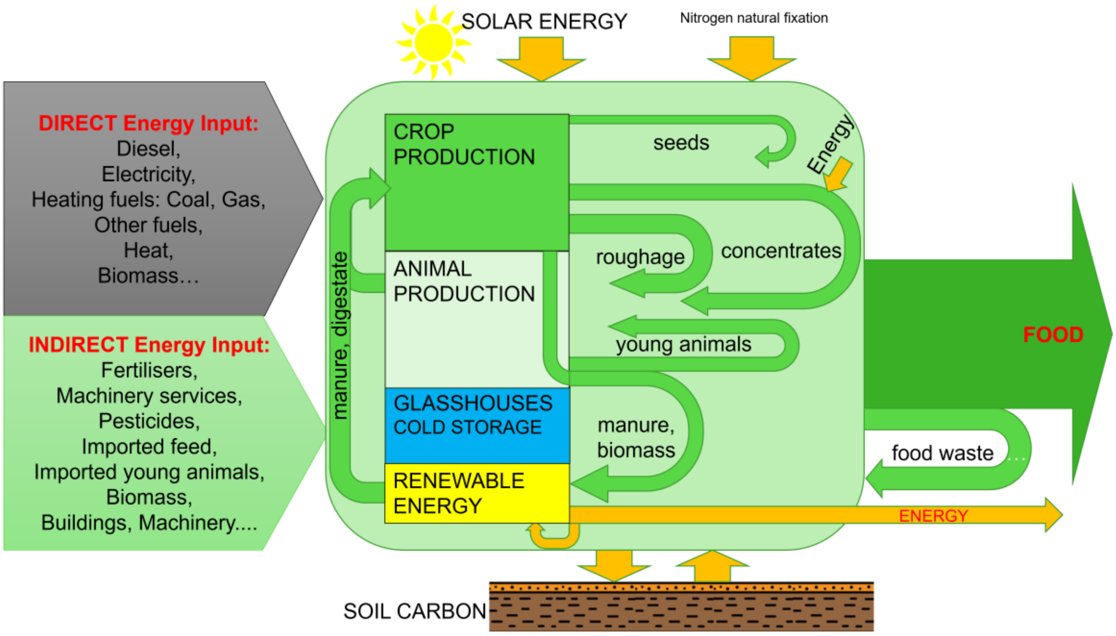

Figure 3 Conceptual framework of energy flow in agriculture at the sector scale (Source: D1.2)

In analyzing the magnitude of energy flows in EU agriculture, D1.2 concluded that farm-level assessment indicators should be applicable across all EU countries, though Cyprus, Malta, and Luxembourg are less significant in terms of overall agricultural energy use. From the list of energy inputs, several were deemed less relevant to AgEnRes project goals due to their minimal contribution to total energy use, their status as fixed costs (e.g., one-time investments), or their price being influenced by factors beyond fossil fuels. These include:

- Pesticides (low share, lack of data on energy content per crop),
- Imported feed (price dependent on many factors),
- Young animals, buildings and production of machinery (once bought, not vulnerable to energy prices).

In Task 1.3, we built on the findings from D1.1 and D1.2 when challenging, refining and complementing the CAP result indicators in light of the project's objectives within the defined framework boundaries.

2.2 CAP Indicator Review and Stakeholder Involvement

Methods

The first review step was an in-depth screening of the pre-selected CAP result indicators identified in D1.2. This process unfolded in three distinct sub-steps:

Screening Project Tasks and Data Needs

All tasks outlined in the AgEnRes grant agreement (GA) were reviewed. Since the project was still in its early stages and many partners had not yet initiated their work, data requirements, knowledge gaps, and potential solutions for each task were derived directly from the project documentation. Model-related tasks were assessed on the basis of the models they planned to use allowing to infer the principle relevance of the selected CAP result indicators to the expected activities. This step resulted in a preliminary collection of required data sources and an overview of the potential for CAP result indicators to be applied to a specific end in the project.

Internal Review and Feedback on Indicators

A collaborative review followed based on a long-list of all directly or indirectly relevant CAP indicators (incl. definition, objectives and unit). The team collected internal feedback from responsible research partners on the quality of the CAP result indicators for analytical purposes. All comments were summarized into generic observations for each individual indicator, focusing on why it might be relevant to the topic and specific tasks including considerations of how indicators could be refined to align more closely with AgEnRes objectives, particularly regarding EU agriculture's energy dependency.

Validation and Workshop with Project Experts

The findings were validated and complemented during a two-hour internal workshop held in September 2024. This workshop involved project experts and focused on refining relevant indicators for policy evaluation, with an emphasis on the CAP result indicators vis-à-vis the specific research objectives in AgEnRes in the frame of the energy-agriculture nexus.

Take-aways

The following section combines the desk research results by the leading team with the refined outcomes of the internal workshop first regarding the data and model requirements, second concerning feasibility and relevance considerations on indicators as assessed by stakeholders during the workshop.

1) Data and model requirements

In this section, we present the data and model requirements identified in September 2024. This overview provides a foundation for further analysis aligned with specific task-related objectives. The requirements will undergo further adaptation and specification as project work develops further.Table 1 outlines key tasks and data requirements in different tasks undertaken in AgEnRes. While the overall objective of the project is gain a better understanding of practical ways to improve energy efficiency and reduce reliance on fossil fuels in EU agriculture, the specific work packages or-tasks operationalize the objectives with different research questions and sub-objectives at different levels. In a nutshell, this diversity in data requirements may be structured along the following lines:

a. **Conceptual approach:** the analytical work in AgEnRes may be captured to follow 3 broader thematic research interest with conceptually distinct approaches to energy independence in agriculture with distinct needs towards data:

   - Assess *energy dependency* (*problematization*): Economic (including historical) data that allows to specify energy costs, energy use, and price fluctuations critical for assessing key features of energy (in)dependency and related risks or opportunities for farming businesses (esp. income) and the agricultural sector (e.g. production) arising from the adoption of energy saving technologies and other innovations on farms.

- Evaluate *energy-saving technologies* (*technical solution*). Assessments of the technological applications require data on aspects such as their economic costs, technical energy saving or emission reduction potentials, technical applicability in various contexts (farm types, climates etc.), and needs to be at a level of detail that allows reflecting regional differences

- Assess the *adoption potential of innovations* (*behavior and decisions*): Studying behaviour based on experiments and surveys draws on a very specific set of data that helps gaining a deeper understanding of farmer decision-making under risk. The data needs a level of detail on decision-making processes that allow for informing the development of tools to manage price risks and encourage innovation adoption in practice

Table 1 Overview tasks in AgEnRes as planned at the start of the project with expected data requirements, sources and availabilities.

Task	Contact	AgEnRes research objectives in task	Model used	Data requirements	Data availability/sources
2.1	INRAE	EU-wide database on (in)direct energy use at different scales		Economic data (costs, quantities) of energy use in farming activities,	FADN/FSDN
2.2	WU	EU-wide database on risk parameters		Historical energy price fluctuation records, risk attitude records	FADN
2.3	AUA	an EU-wide web database focused on energy-saving technologies will be developed		Attributes of technologies (farm level, costs, mitigation potential, impact on farm management, regional differences)	Task 1.2, other data bases (e.g. non-CO2 EPA GHG Data protocol, EB Open data)
3.1	SLU	"fossil energy dependence" measures and evaluate the energy-use efficiency at different scales		Cost shares of (in)direct energy use for micro and regional scale	T2.1, EUROSTAT, NUTS2/3, FADN/FSDN
3.2	INRAE	Assess the impact of price fluctuations of energy-intensive inputs on energy dependence		Historical energy price fluctuation data, input demand, transmission mechanisms, food supply, risk attitudes of farmers	FADN, T3.1, T2.2
3.3	WU	Assess the shadow price of reducing (in)direct energy use on pollution.		Production framework, data on profits, pollution, energy use for various scales	T3.1.1, FADN
4.1	UNITN	Identify adoption potential of innovations		Data on innovations, interviews/survey data from 300 farmers	T1.2, surveys
4.2	AgroApps	Development of a decision support system for energy dependency and GHG emissions assessment		Available innovation (reduced fossil inputs /emissions); Data on costs, site-specific adoption requirements, energy and emission saving potentials	T1.2, T2.3, T4.1, farm data via UI
5.1	UNITN	Systematic literature review on farmers' mineral fertiliser decisions under risk		Scientific literature on farmer decisions under risk	/
5.2	WU	Systematic literature review on farmers' adoption of price risk management instruments		Scientific literature on adoption of price risk management instruments	/
5.3	SLU	behavioural economics concepts to advance understanding of farmers' preferences and their relation to input and price risk management decisions in crises.		/	farmer elicitation experiments
5.4	WU	Development of input price risk management tools for farms including an assessment of their risk reduction potential		Information on farmers preferences / choices reg. price risk management tools in crises; risk reduction potential of tools	T4.1-4.3, FADN

5.5	UNITN	Behavioural finance experiment for ex ante assessment of WTP for innovative price risk management tools		Risk reducing properties of risk management tools; data from behavioural experiments	T5.4; contribution of 300 farmers
6.1	SLU	Translate findings from behavioural economics and experimental insights to modelling	FarmDyn, AgriPoliS	Results from behavioural experiments	WP 4, 5
6.2	WR	Determining optimal short- and long-term production and investment decisions	FarmDyn	Farms level data (of most affected regions, comparable farm types, case study results for validation)	FADN/FSDN, synthetic data, cost accounting data from WP2
6.3	IAMO	Interdependence between new energy-saving investments and farm structure	AgriPoliS	Empirical data for NL, GER and POL, results from behavioural experiments, developed risk management tools	FADN, FSS, national census data, WP4,5
7.1	IIASA	Calibration & integration of EU-level economic, agricultural, energy, and macro-economic models for scenarios of future fossil fuel use in agriculture	GLOBIOM, PRIMES, GEM-E3	Direct and indirect fossil fuels use data, farm-level models	WP2, WP6, EU Reference Scenario 2020
7.2	IIASA	Enhanced representation of fossil fuels dependence reduction technologies in integrated assessment modelling framework.	GLOBIOM, PRIMES, GEM-E3	Parameters on fossil fuel dependence reduction technologies 3 (costs and potentials of energy saving technologies), adoption behaviour and risk in this behaviour; ex-post and ex-ante farm-level modelling results	T2.3, T2.2, WP3-5
8.2	WR	Stakeholder involvement and participatory development of modelling activities	FarmDyn, AgriPoliS, GLOBIOM, PRIMES, GEM-E3	/	/
8.3	WR	Policy evaluation: Impact assessment of policy instruments to reduce fossil energy dependency	FarmDyn, AgriPoliS, GLOBIOM, PRIMES, GEM-E3	Finished set of models and scenario results	T8.2, all previous WPs

b. Level of analysis:

- Micro/farm-level: detailed data on production, energy use, and investments is essential for analyzing and better understanding (modelling) the farm context of (risky) decisions including the impacts that farm structure but also farmer behavior and attitude have on energy dependency and energy-saving potentials

- Macro-level: Macroeconomic and agricultural models are integrated to project energy scenarios and evaluate the impact of energy-saving technologies at scale and in the context of the overall economy. These rely on data tracking sector-wide fossil fuel use and technology adoption as a basis for developing realistic national to EU-level strategies.

c. Data sources: Overall the data needed and used in AgEnRes according to the different levels of analysis and research interest is highly diverse and translates into a variety of relevant data sources for assessing and developing tools and (political) strategies for promoting sustainable, energy-efficient farming. The concrete research interest and method of analysis are decisive for what data sources may be used (including existing) in practice

- For instance, for farm-level data focused at economic, technical (and partly behavioral) analysis (energy costs on farm, energy use, farming practices) key sources include the Farm Accountancy Data Network (FADN), EUROSTAT, and related datasets.

- By contrast, for elaborating on the technical features of energy saving technologies open databases like the non-CO2 EPA GHG dataset may be useful.

- For historical analyses (e.g. price fluctuation) cost records are a primary source

- In other cases, data needs to be “built up” drawing on sources that have to be created either artificially (synthetic datasets) or by reviewing, processing and interpreting existing empirical data (literature incl. regional case studies) or be collected in own survey or experiments

2) Feasibility and Relevance of indicators

Bearing in mind own data requirements for the analytical work in subsequent tasks, AgEnRes researchers were invited to reflect upon the existing indicators in use in agriculture policy as a basis for developing them further for addressing energy dependence based on common grounds in research and practice. To this end the short-list of CAP result indicators from D1.1 was extended to a long-list of 18 indicators (see appendix 0) deemed at least indirectly relevant for AgEnRes and the agri-energy nexus addressing fossil energy dependence, extending even to subjects like knowledge and capacity building measures or risk management. In a grid format the feasibility and relevance of each indicators was assessed. Figure 4 provides a snapshot of the interactive process employed in the Online “Miro board” tool to reflect jointly with participants on the utility of CAP indicators and scope for improvement and common grounds with analytical interests in the subject from the perspective of the AgEnRes objectives.

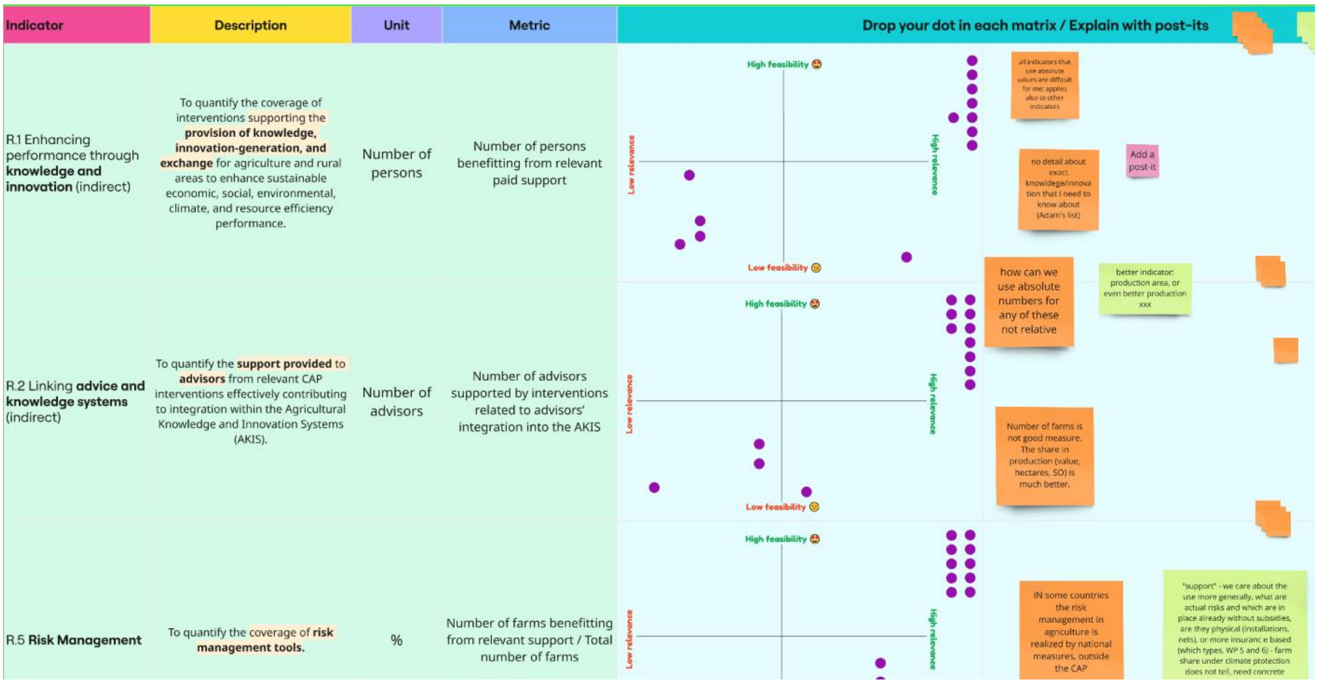

Figure 4 Illustration of the Miro board on indicators evaluation at the internal workshop.

The board was arranged as a visual matrix to allow participants evaluate specific indicators based on shared principles. The first column lists the key indicators (here, e.g.: knowledge and innovation enhancement (R.1), advisory support integration (R.2), or the adoption of risk management tools (R.5)). The column "description" summarizes each indicator's objectives, such as supporting the provision of knowledge, whereas the "Unit" reflects the specific data used to measure the achievement of the objective, e.g. the number of beneficiaries (of advisory services) or the percentage of farms adopting a certain practice or innovation. The column metrics details the exact measures used as the CAP indicators to track or assess the performance towards the objective, e.g. the number of advisors, the share of farms receiving support, or the percentage of farms implementing risk management tools. On the far right, a feedback section allowed participants, using sticky notes, to provide their judgments of these indicators not only for CAP monitoring, but for their analytical interests within the agri-energy nexus. Sticky notes also allowed attendants to specify their judgement of metric feasibility and to provide concrete suggestions for refinement in line with the AgEnRes objectives.

The results in Table 2 show that none of the reviewed indicators received a fully positive assessment. Most indicators focus on basic metrics, such as the number of farms or areas benefiting from CAP funding, and face two key issues: Insufficient rigor for tracking trends over time and limited insight into specific policy impacts regarding the actual policy objective at the energy-agriculture nexus. Indicators based on relative values, like the share of utilized agricultural area (UAA) receiving payments, were described as being more insightful than absolute figures like total hectares. Discussants also noted that it remains broadly unclear which services are included exactly when generically referring to knowledge transfer, innovation, or risk management tools, and how difficult it was to assess their quality or impact with regard to energy dependence.

Indicators for risk management, farm modernization, renewable energy, climate investments, sustainable nutrient management, or organic agriculture were found to be principally highly relevant but also required better measurement methods. For example:

- the Risk Management indicator lacks specificity and varies across countries.

- Farm Modernization would be clearer or more useful if tied to production areas rather than farm numbers.
- Renewable Energy should emphasize and specify investment per technology rather than total energy output.
- Climate Investments should focus on specific types of investment instead of farm counts.
- Sustainable Nutrient Management is well-defined with no major issues.
- Organic Agriculture, though less directly relevant, helps compare energy efficiency between organic and conventional systems, even if organic farming may not be fossil-free, eventually.

The described limitations of CAP results indicators for use in AgEnRes should not be perceived as a general lack of utility for policy. Rather their mismatch with analytical requirements in AgEnRes reaffirm the insights from Deliverable 1.1 that existing policies and support measures – including their approaches to monitoring – do not reflect well the relevant considerations at the energy-agriculture nexus with regard to achieving fossil energy independence. While the indicators are generally relevant, they need considerable adjustment and refinement to improve precision and adaptability for better assessments of sustainable agricultural practices that are able to reflect progress towards independence from fossil-energy inputs and price volatility.

Table 2 Most relevant CAP Result Indicators for the agri-energy nexus as reviewed at first internal workshop

Indicator	Description	Unit	Metric	Relevance	Feasibility	Comments
R.5 Risk management	To quantify support of risk management tools	%	Number of farms benefitting from relevant support / Total number of farms	High	Low / Medium	• Very important indicator • Risk management often regulated at national level, outside CAP –depends on country (example POL: national obligatory insurance: national subsidy) • Concrete list of risk management tools required rather than generic coverage • Some prefer indicating which risks are present
R.9 Farm modernization	To quantify support interventions for farm modernization, including to improve resource efficiency	%	Number of beneficiaries receiving relevant support / Total beneficiaries	High / Medium	Medium	• Important indicator – but inappropriate unit (share in farm numbers • Production area would be better • Specific type of modernization missing impacting on degree of resource efficiency /fossil fuels /fertiliser use
R.15 Renewable energy from agriculture, forestry, and other renewable sources	To quantify supported investments in RE production capacity, including bio-based	MW	Total installed capacity of renewable energy production supported by the CAP	High / Medium	High	• Better measure supported investment per technology rather than for all RE production • Relevant, but country specific (e.g. natural differences between countries) • Trade-offs: e.g. energy crops for biofuel production
R.16 Investments related to climate	To quantify support contributing to CC mitigation and adaptation, to RE or biomaterials production	%	Number of farms receiving relevant investment support / Total number of farms	High / Medium	Medium	• Type of investment is more relevant than share of farms benefiting from CAP investment support
R.22 Sustainable nutrient management	To quantify commitments related to improved nutrient management	%	Number of ha under improved nutrient management practices / Total UAA	High / Medium	High	*N/A*
R.29 Development of organic agriculture	Share of UAA supported by the CAP for organic farming, with a split between maintenance and conversion	%	Composed of Share of UAA supported for: (1) organic farming; (2) organic maintenance; (3) organic conversion	Low / Medium	High	• Organic not “fossil-free”; e.g. energy use increases in switch pesticides à mechanical weeding • Reducing chemical fertilizers à more energy use • Useful comparison energy efficiency in organic vs. conventional farms

3. Science-Policy Indicators for Energy-Dependence in Agriculture

The CAP result indicators review and feedback workshop highlighted clear shortcomings of indicators in practical use in agricultural policies. After concluding the review of CAP result indicators and identifying their limitations with regard to the research objective, we shifted focus to the scientific perspective on policy evaluation at the agri-energy nexus. The intention was to distil key analytical approaches to policy assessment, and particular relevant metrics of measuring, from the existing body of literature and to elaborate in how far these are of relevance and utility regarding the specific project objectives in AgEnRes including as a basis for data-based exchange between science and policy on the particular issue of fossil energy dependence.

3.1 Literature review method

AI tools for literature pre-screening

In this review innovative technologies like artificial intelligence (AI) were used during the review process to allow for a comprehensive screening of relevant indicators in use in research practice within a rather short period of time. The role of these technologies for reviewing is already widely discussed in the scientific community (Pearson, 2024). An appropriate tool for internet-based search aligned to our purpose needed to not only help processing a vast body of literature efficiently and focused, but to still keep the required scientific rigour. Therefore, we first identified an array of tools at various stages of development which were already mentioned in literature or web resources (Bolanos et al., 2024; Stapleton, 2023; Zala et al., 2024). Overall 15 tools were gathered and reviewed for their accessibility and ability to be used in scientific reviews (Table 3). While most of them are accessible for free, quite some are limited without acquiring the paid version. A general limitation found is the access to literature. Most tool act as a search engine themselves and promise to find more relevant literature for example based on other studies marked as relevant. Other tools even extract relevant information from the studies. However, it remained unclear whether these tools are fully able to access literature from journals with restricted access. Another limitation found was the specificity of some tools, which are often designed for a specific field of research (e.g., System.ai; *not accessible anymore*). For these reasons, ASReview was selected as best choice (44 results to "ASReview" in WoS on 06.12.2024), which is already broadly applied in scientific literature.

Table 3: Overview of all AI tools reviewed in spring 2024 and considered as candidates to be used during the literature review.

AI TOOL	LINK	ACCESS	DESCRIPTION
ELICIT	Elicit: The AI Research Assistant	paid	Language model-based AI tool that helps searching, summarizing and extracting data from literature at modest price. Tutorial https://www.youtube.com/watch?v=6C6wJfvvPlw
RESEARCH RABBIT	ResearchRabbit	free	Add a paper to add notes and get recommendations, powerful visualizations, automatic alerts on new papers. Can access the following databases: PubMed, SemanticScholar
SYSTEM.AI	System | Search Reinvented for Research™	free (limited)	Quick summaries of studies, Synthesis of the research, Systems maps of topics. Can access the following databases: 35 million studies on PubMed

ASREVIEW	ASReview – Active learning for Systematic Reviews	free	Open source software that makes reviewing faster by training a machine learning algorithm to rank documents from most to least relevant based on their content and can save 95% of reading
IRIS.AI	Iris.ai - Your Science Assistant	free	Exploration tool that provides an overview of scientific knowledge sorted by relevance related to a research topic. Can access the following databases: "CORE" Database of open access literature
COLANDR	Colandr Community - Home	free	Smart-sorting citations by relevance for inclusion at subsequent stages of the review and classification of included documents for user-defined categories
LITBASKETS	Litbaskets		Development of search methodologies
LITSONAR	LitSonar		Allows syntax interpretation of queries between database servers & creating reports
ROBOTREVIEWER	RobotReviewer		Automating evidence synthesis
WEBPLOTDIGITIZER	automeris.io		Extracting data from statistical plots
GRAPH2DATA	Graph2Data (meassoft.com)		Extracting data from statistical plots
REVMAN	Cochrane Account Login		Testing of hypotheses
DMETAR	Companion R Package for the Guide Doing Meta-Analysis in R • dmetar (protectlab.org)		Doing Meta-Analysis in R
SCISPACE	AI Chat for scientific PDFs | SciSpace (typeset.io)	free (limited)	Find, understand, and learn any research paper. For every paper get simple explanations and answers from AI and discover a network of connected and relevant papers. Can access the following databases: A repository of research papers across domains, with metadata of 200 million+ papers and 50 million+ Open Access full-text PDFs
CHATPDF	ChatPDF - Chat with any PDF!	free (limited)	Answer questions and understand research

ASReview (ASReview LAB developers, 2024) was developed at Utrecht University and uses state-of-the-art active learning techniques to efficiently screen large amounts of text. It assists in providing an overview of the most relevant records, while maintaining transparency in the process. It supports multiple machine learning models and is designed to be easily extensible. Zala et al. (2024) described the tool as "*A tool with minimal limitations, stands out as a promising option for IS researchers. Operating on health sciences databases and requiring PubMed IDs are not significant limitations for ASReview. This tool, developed recently, is noteworthy for its transparency (under the Apache-2.0 License), script accessibility (implemented in Python), and the ability to easily integrate new features.*"

The software requires a downloaded list of literature from a search engine (e.g., a .ris file) containing titles, authors, publication year, and abstracts. Reviewers categorize each study as "relevant" or "irrelevant" based on the title and abstract. ASReview then uses this input to learn and reorder the remaining literature, prioritizing likely relevant studies at the top. As the process advances, the tool can automatically classify some studies as irrelevant based on exclusion criteria it has learned.

In our case, two team researchers independently reviewed the literature using ASReview. Discrepancies in their ratings were re-evaluated collaboratively to determine inclusion or exclusion during the full-text review.

Search query

The search for peer-reviewed papers was conducted using the Web of Science Core Collection, covering all editions and fields. The query targeted papers on policy indicators applicable at the farm level, aligned with overall policy goals, and closely related to relevant CAP indicators, as shown in

Figure 5. Each coloured section corresponds to a search focus or inclusion criteria for the review. Conducted on August 14, 2024, the literature search identified 274 studies, which were reviewed in the first step using ASReview as outlined above.

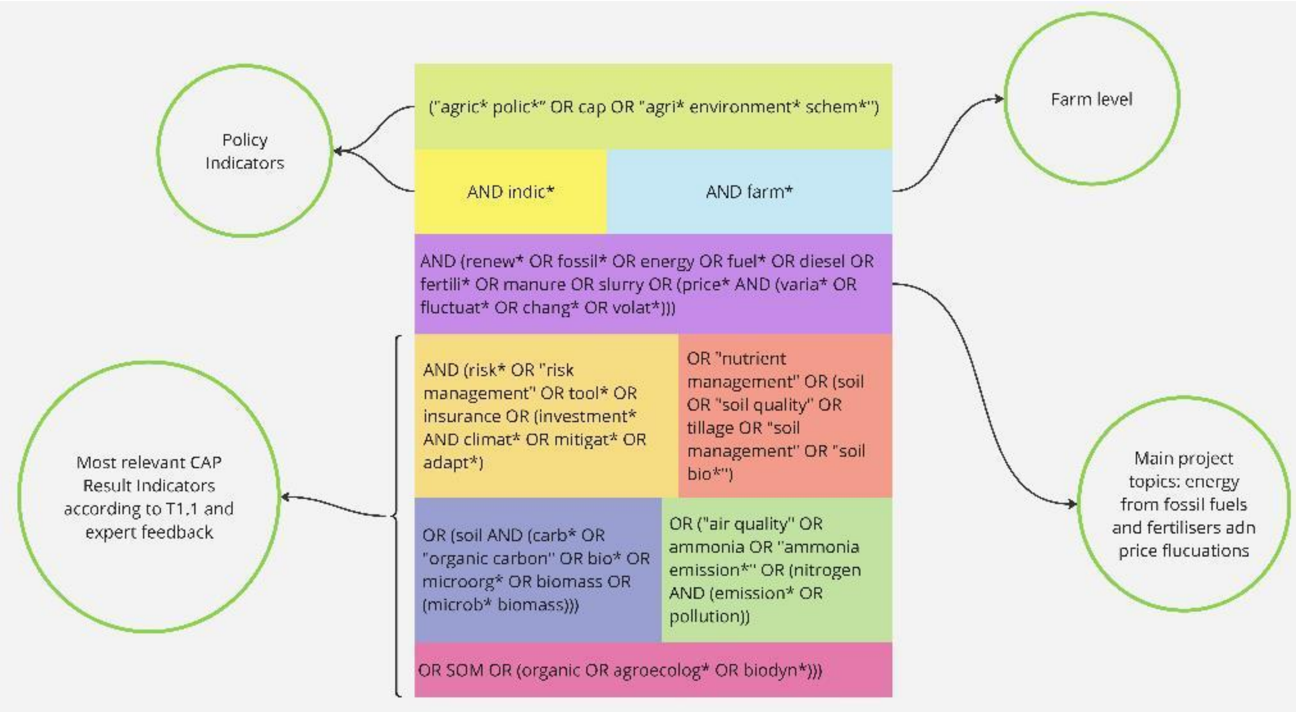

Figure 5: Search query used to gather studies for the indicator literature review.

Full text screening

After AI-assisted abstract screening, 65 studies remained for detailed review. These were evaluated independently following a group review of the initial studies, with unclear aspects resolved through separate discussions to ensure unanimous decisions.

The studies were assessed based on inclusion and exclusion criteria defined by the task goal and the framework outlined in D1.2. Inclusion criteria focused on direct energy inputs such as diesel, electricity, and heating fuels used in crop production processes (e.g., tillage, irrigation, crop maintenance). For glasshouses, energy consumption included electricity and heating fuels for operations like cooling and crop storage. In animal production, the focus was on electricity and heating fuels for activities such as feeding, manure removal, and milk cooling. Indirect energy inputs, including energy for producing NPK fertilizers and operating machinery, were also considered. Excluded factors included pesticides, imported feed, young animals, and fixed assets such as buildings and machinery.

Inclusion Criteria:

1. **Relevance to Energy Use:** Articles must focus on energy use in agricultural activities, including crop production, glasshouse operations, animal husbandry, or fertilization.
   - Specific processes:
     - *Crop production (direct):* Diesel and electricity for tillage, irrigation, and maintenance.
     - *Glasshouses and cooling (direct):* Electricity, heating fuels, or diesel for operations and storage.

- *Animal production (direct):* Electricity and heating fuels for feeding, manure removal, etc.
- *Fertilization:* Indirect energy use (e.g., electricity, methane, diesel).
- *Service costs:* Indirect energy use in machinery maintenance.

2. **Time Frame:** No limitations.
3. **Farm Types and Economic Sizes:**
   - Farm types: Field crops, horticulture, wine, permanent crops, milk, grazing livestock, granivores, mixed.
   - Economic sizes: Small (€2,000–€8,000), Medium (€25,000–€50,000), Large (≥€500,000).
4. **Regions:** EU-27, Switzerland, and the UK.

Exclusion Criteria:

1. **Non-Related Studies:** Articles that do not address energy use in the specified agricultural activities.
   - Unrelated activities: Pesticides (low share, limited energy data), imported feed (price-dependent on multiple factors), young animals, buildings, and machinery production (not energy price-sensitive after purchase).
2. **Regions:** Cyprus, Malta, Luxembourg, and non-EU countries.

Following these criteria, 20 studies were excluded during the text review, resulting in 45 included studies, as shown in the PRISMA diagram (Figure 6 PRISMA Diagram of the review process as proposed by Haddaway et al. (2022)Figure 6).

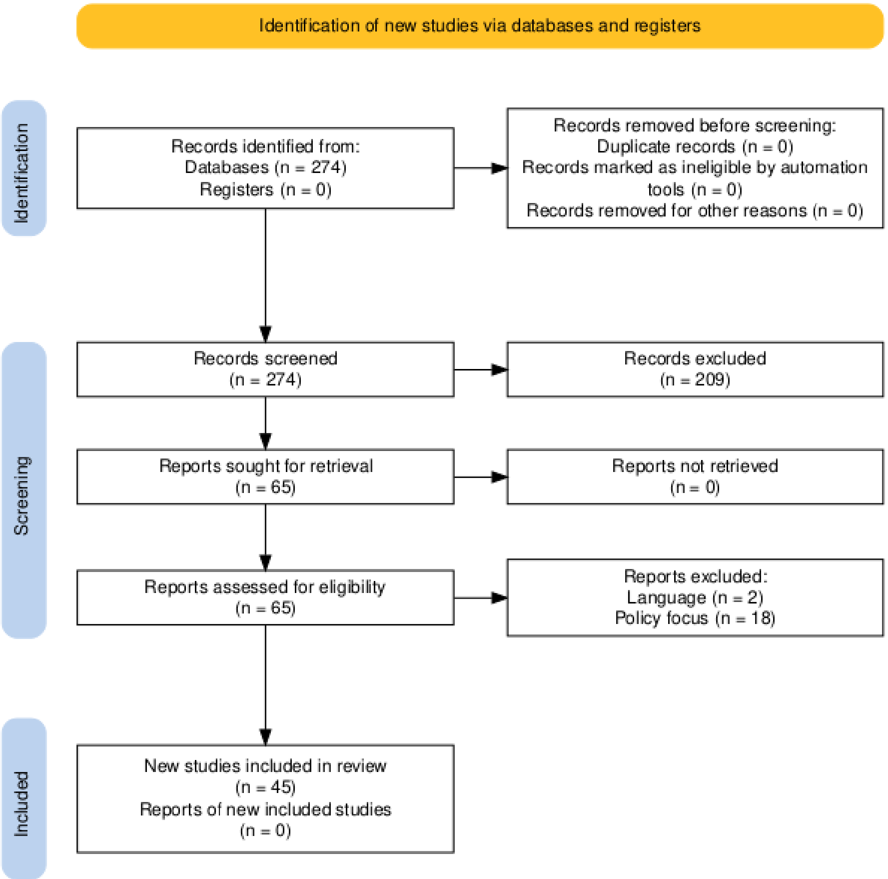

Figure 6 PRISMA Diagram of the review process as proposed by Haddaway et al. (2022)

Indicators

We compiled all relevant indicators identified in the studies, organizing them in a matrix where each row represents a unique indicator from a specific study. For each indicator, we documented details such as the country and scale of application, the policies addressed in the article, the dimension (environmental, social, economic, governance, or mixed), and the unit and method of measurement (Schreefel et al., 2024).

3.2 Stakeholder engagement

A second workshop was held with external experts to further refine the list of indicators for policy evaluation at the agriculture-energy nexus on the basis of the insights and patterns seen from the literature review. The online based AgEnRes workshop with stakeholders "AgEnRes Workshop: A harmonized energy indicator list for science-policy exchange | AgEnRes" took place on 25 November 2024 and lasted 90min. 12 out of 20 confirmed external participants participated eventually. An additional 14 experts from the consortium joined the in depth-discussions in this science-policy dialogue. The workshop was oriented at researchers, policy makers, or civil society representatives working on climate, energy and/or agricultural policies – either at EU or at national level (in Europe). Some of the participants were recruited through the AgEnRes Stakeholder Advisory Boards or were already engaging in earlier work. For data protection reasons no list of participants can be shared beyond generic information such that their range covers different relevant sectors including academia, farming associations, policy making and administration which allows practice-proofing and enriching the insights on indicators considering diverse views and perspectives.

The workshop followed an approach inspired by *Structured Decision Making* (SDM) (Gregory et al., 2012), which prioritizes defining goals and objectives before exploring solutions. The primary objectives were to identify goals, explore potential issues, and assess stakeholder consensus or disagreement on the proposed indicators, including understanding the reasons behind differing viewpoints. Gaining a better understanding of what was a good indicator for different stakeholders – including their ends in science and practice was key to critically evaluating the types of indicators identified in literature. The process followed six steps (detailed in Annex 0).

Overall the second workshop was designed around two major objectives: (a) defining goals for policy indicators and (b) evaluating key indicators identified in literature review from varying stakeholder perspectives. This way the workshop aimed at "confronting" stakeholders with the results of the literature review to spark reflection on their utility in science, policy and practice including allowing for a deeper dive into underpinning principles and justification for assessing indicators as 'good'. One key output of the workshop was a range of conceptual considerations on the quality or function indicators relevant for policy assessment in the agri-energy nexus. A more concrete second output were the specific features or metrics which make indicators practically useful including considerations of pertaining limitations, gaps or trade-off.

After a short introduction to the project and work package and the online interactive tool Miro (www.miro.com), participants were invited to engage in 2 rounds of discussion to explore: 1) the **goals of policy indicators** specifically considering the objectives at the agri-energy nexus. 2) the **quality of existing indicators**, specifying the requirements for evaluating specific indicators as 'good' and adding indicators to fill gaps or address pertaining challenges.

3.3 Science-policy indicator long-list and evaluation

Contextual elements

A total of 175 unique indicators were extracted from 45 included studies, with individual studies often containing multiple indicators. While some studies were using similar indicators they were still recorded individually. The Indicator Dataset with the full list of indicators (Oggiano et al., 2025) is publicly available *here* while the list of studies used is found in Table 8 in the supplementary material at the end of this report.

The frequency of topics addressed by the indicators will be discussed further in the next section. Figure 7 highlights the involvement of various EU countries in the reviewed studies, shedding light onto the spatial distribution of policy research. Poland and Italy stand out as the most frequently studied national case studies. Apart from individual country contributions, EU-wide studies represent a significant portion of the research. These studies emphasize broader initiatives and policies that span multiple countries, indicating a concerted effort to analyse collective EU strategies. By contrast, regions such as Greece, the Western Balkans, and Slovenia are minimally represented in the sample, suggesting either a lower research output from these areas or limited attention paid to policies specific to these regions.

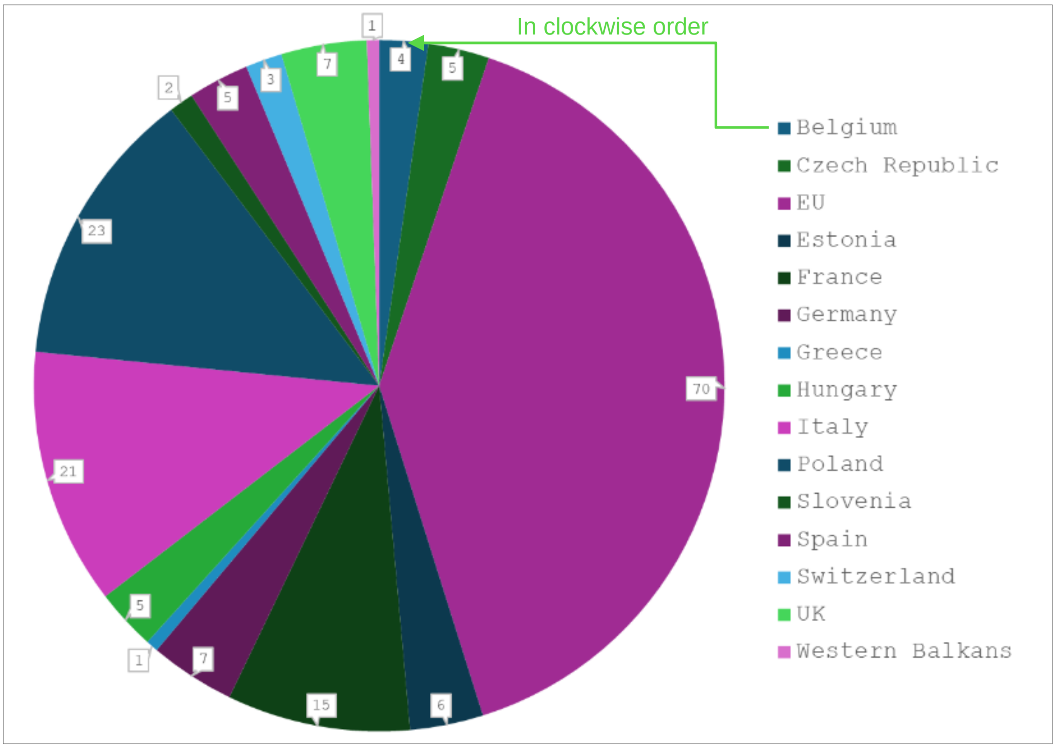

Figure 7 EU/Country covered in reviewed studies.

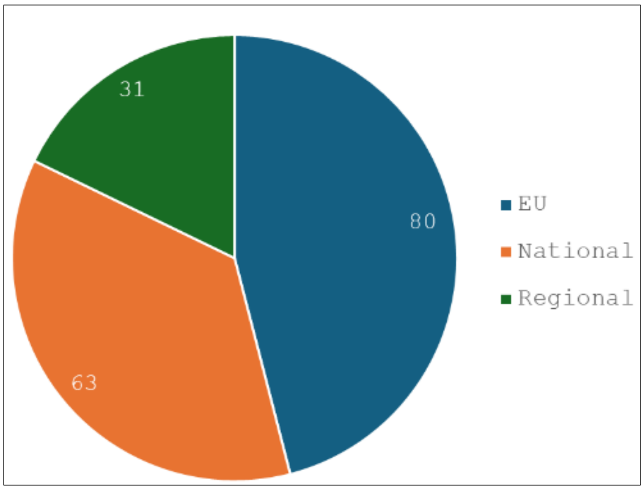

Figure 8 Level to which policies are assessed by 175 reviewed indicators. (1 indicator not applied on a specific study and thus not represented in the figure.)

The distribution of levels to which policies are addressed in the studies is displayed in Figure 8. The policies are categorized into three distinct levels: EU, national, and regional. Among these, EU policies dominate, with 80 indicators being applied at this level. This finding underlines the importance of analysing EU-wide strategies that impact multiple member states. National-level policies or EU policies specifically applied at national levels were studied employing a total of 63 indicators.

The regional level is the least studied with only 31 indicators addressing this level. This limited focus suggests a research gap in analysing strategies customized to the local level potentially leaving important subnational dynamics underexplored. In summary, few studies from the literature review actually assess very specific regional and also national policies without direct linkages to European policies. From the 175 indicators in the list, only 16 make explicit references to specific regional or national policies, without direct linkages to EU policies as such. These more specific policies comprise, among others, the German Renewable Energy Sources Act (EEG) and various French environmental targets. In terms of policies applied and/or specifically customized or translated at national or regional level, but still referring clearly to the EU framework, these include for instance policies designed in relation to Agri-Environmental Schemes (AES) or Rural Development Plans. Therefore, EU policies largely dominate or have a high influence on the studies and indicators included in the review.

Indicators

Moving on to the indicators themselves, they can be categorised according to their topical application areas and methodologies in both data collection and ways of obtaining the results.

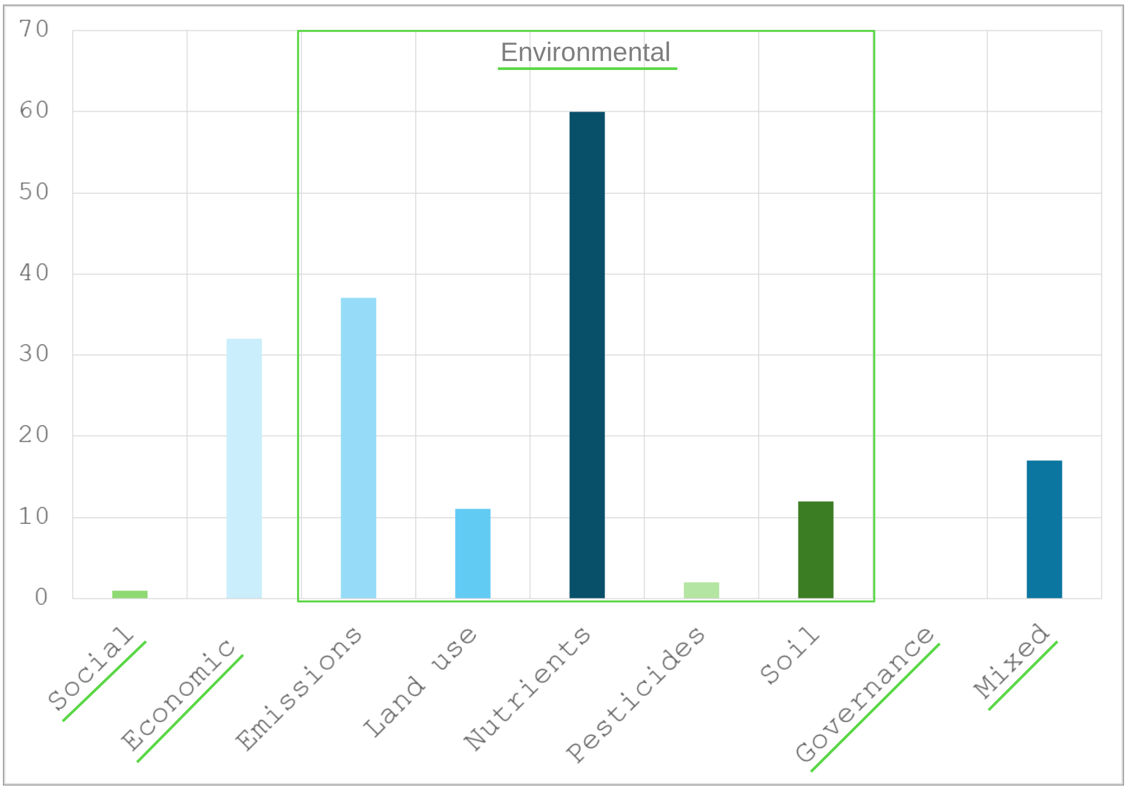

Figure 9 Frequency of indicators within target topics identified in literature review.

Source: own review data; the topics are build based on the four dimensions of sustainablity (social, economics, governance, mixed) as well as sub-dimensions to provide more context to the environmental dimension.

Figure 9 represents the thematic distribution across indicators arising from the literature review. There is a clear dominance of indicators measuring environmental aspects. In order to better reflect the inherent diversity, we divided this category further into sub-categories. “Nutrients” is by far the most frequent sub-topic, encompassing 60 indicators. This indicates that significant research effort is devoted to understanding and managing nutrient-related issues in the environmental and agricultural context. Other sub-categories, such as “Land Use”, “Soil” and “Emissions”, also receive notable attention, though they are targeted less frequently compared to “Nutrients”.

In addition, the other broad categories, i.e “Social”, “Economics” and “Mixed” are targeted much less frequently compared to the “Environment” one. or even without any entries. Interestingly, 17 indicators were classified as “Mixed”, meaning to measure a combination of aspects from the four sustainability categories, where mostly environmental and economic metrics were combined (see examples in Table 5). Lastly, “Governance” stands out as the least studied category, indicating a significant research gap in this area.

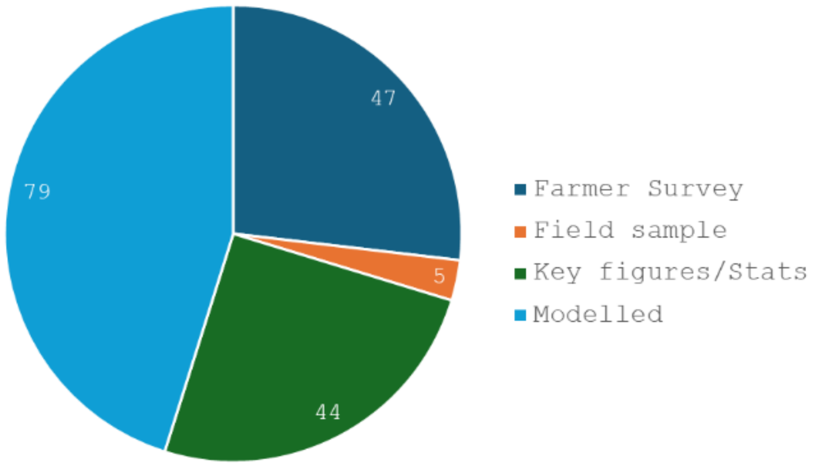

Figure 10 Measurement methods for indicators and their frequency as found in the literature review.

In terms of methods, most indicators are results of modelling exercises (79 indicators/ 45%, **Fout! Verwijzingsbron niet gevonden.**), where the performance of farms is derived from a combination of various data sources. Further, farmer surveys emerge as a widely used method, with 47 indicators utilising this approach.

Key Figures/Stats is applied similarly often (44 indicators). This method involves leveraging existing datasets, reports, or publicly available statistics to analyse the performance of policies. In contrast, field sampling, a method that requires considerable direct or resource-intensive data collection is used far less frequently (5 indicators/ 0.03%).

Moving on to the indicators themselves some patterns of more frequent topics became visible when scanning through the long list of indicators. Main findings for each category are the following:

Environmental

Emissions

- Nearly all indicators relate to GHG modelling using various functional units and measured at different scales.
- Even though methodologies sometimes allow to separate sources of GHG (i.e., contribution analysis in LCA), only a few indicators specifically focus on GHGs related to (direct or indirect) fossil fuel consumption.

Land Use

- Mostly related to the area under a certification scheme (i.e. organic agriculture, integrated production, ecological zones within agricultural area (UAA)).
- Only rather indirect link to energy dependency.

Nutrients

- Vast majority of indicators focuses on nitrogen in this sub-category. Phosphor is the second one in much smaller numbers.
- Indicators estimate N inputs, balance and surplus mostly at farm level, but regional and national level assessments are also found. The metric used is usually kg N ha^{-1}.
- Most indicators are derived from modelling outputs.
- Only very few indicators focus on changes in nutrient inputs (i.e. reduction in inputs), nutrient use efficiency or the share of nutrients from mineral or organic sources.

Soil

- Most indicators refer to soil organic carbon (SOC) contents: Total SOC (%), changes of SOC in a year, qualitative evaluation of the levels of SOC found.
- Nearly all indicators were measured through field sampling.
- Limited focus on used tillage practices, which could be direct energy use indicators allowing to infer on more qualitative aspects such as SOC or soil biodiversity.

Economic

- Main indicator topics are farm income/profitability, expenditure on inputs (mainly fertilisers)
- More complex modelling involved, typically looking at marginal revenue/abatement costs or change in production/income/expenses.
- A small number of indicators goes beyond these above-mentioned topics and addresses other aspects like the level of subsidies dedicated to adoption of high efficiency practices, expenses on various fossil energy sources, or risk related indicators. Particularly the latter represents a gap in the list, since it is a central aspect in AgEnRes

Social

- Only one indicator measuring the level of adoption of innovative technologies.

Mixed

- Indicators in this section span multiple of the above-mentioned categories and can be more complex (e.g. energy, efficiency).
- Most relevant indicators combine environmental and economic concerns (e.g. eco-efficiency)

Overall the list of indicators is quite comprehensive on the environmental and economic side. Key environmental concerns like nutrient pollution and greenhouse gas emissions, and economic topics like farmer income, are addressed frequently. Furthermore, a limited number of indicators are specifically targeted at energy use and related dependency of the agricultural sector. Beyond that, the social and governance aspects are poorly represented.

A major question concerns the (potential) utility of these indicators–when considering the project objectives. This offered a unique opportunity to work with the extensive indicator list and discuss the requirements in the context of policy evaluation indicators to be used within the agri-energy nexus. This was addressed in an expert workshop, which is elaborated on in the following section. In the external workshop the most prominent example indicators per dimension (e.g. social) were represented to reflect the "core metrics" that science is currently concerned with (Figure 11). Considering the vast number of environmental indicators in academic literature, these were discussed along the most iconic sub-categories (e.g. soil, emissions, nutrients, land use).

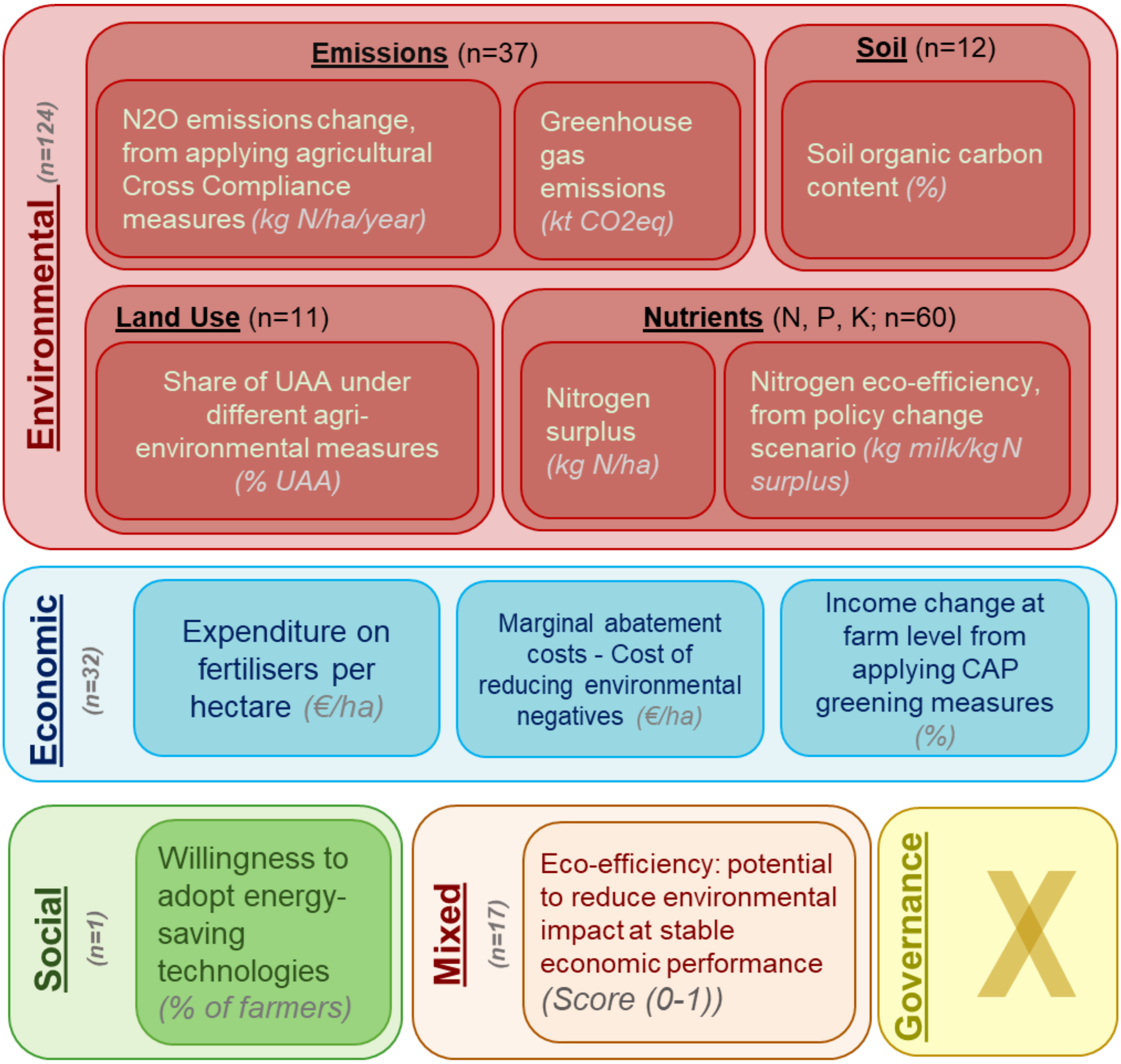

Figure 11 Sub-types of environmental, economic, social and governance and mixed indicators with most prominent examples for metrics/units

3.4 Insights from the external workshop

A) Goals of policy-indicators at the agriculture-energy nexus

Workshop attendees were invited in outbreak groups to define specific goals to achieve through policy indicators classified along key sustainability dimensions (social, economic, environmental, governance and mixed). Figure 12 illustrates the set-up of the Miro board for implementing this exercise with participants. Focus was set on the indicators themselves rather than the policies being assessed. The objective was to step back and examine the role of policy indicators in evaluating policies.

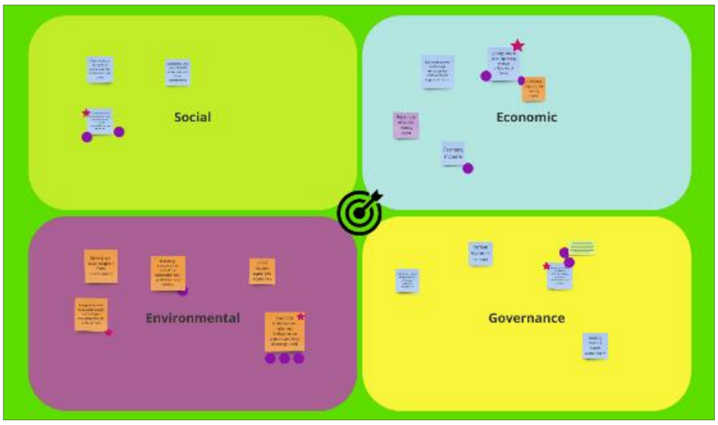

Figure 12 Miro board for 'goal identification' exercise

From a social perspective, particular emphasis was placed on the role of communication and raising awareness. A well-designed indicator effectively conveys the implications of policy interventions to citizens, empowering them to act or voice concerns about policy impacts. For directly affected groups, such as farmers, clear and accessible indicators help understanding how policies influence their actions and outcomes. Additionally, useful indicators help reveal the behavioral drivers, particularly regarding the adoption of new technologies. Given the agricultural sector's role in food production and security, society receives valuable insights as to how policies impact on essential goals.

From an economic perspective, experts emphasized that policy indicators should primarily aim at improving efficiency—both within agricultural enterprises and in public spending. Identifying the most cost-effective policies is key. Energy-related indicators, for instance, need to measure farms' energy inputs, distinguishing between direct and indirect energy use, as well as between fossil and biogenic sources. Experts also expressed a preference for indicators measured in monetary units to facilitate their use in models, such as those required by the AgEnRes project.

In the environmental dimension, indicators ideally allow for evaluating changes in environmental impacts targeted by policies, including the possibility to capture potential trade-offs. Relevant metrics are greenhouse gas (GHG) emissions, water and air quality, or impacts measured per unit of area or product. A systemic approach is necessary to avoid that policies unintentionally shift impacts to other subject areas or geographical regions. Indicators need to be able to identify negative externalities while highlighting synergies and trade-offs with other policies, such as those promoting bioenergy or renewable energy production (à mixed). Furthermore, indicators should reflect agriculture's potential to offset some of its own emissions.

On the governance dimension, governments should ensure transparency and accountability in democratic policymaking processes. Public accessibility (transparency) of performance indicators at regional levels marks a goal in its own right for effective policy. Experts noted a persistent lack of adequate monitoring tools in many countries, with current CAP indicators often insufficient for national-level assessments.

A general feedback to indicators categorized as "Mixed," was the need for simplified data collection to reduce administrative burdens and enhance cost-efficiency. Additionally, indicators should illuminate trade-offs between sustainability dimensions to ensure policies align with overarching sustainability goals. As noted in other deliverables (D.1.1), existing EU policy frameworks often hinder such integrated approach by prioritizing conflicting objectives (e.g. fossil fuel subsidies). Table 4 summarizes the goals that participants have elaborated along the 5 dimensions.

Table 4 Goals for policy indicators across dimensions as defined by workshop participants

Goals per Dimension
Social • **Clear communication** of policy impacts to empower citizens and stakeholders (e.g., farmers), incl. in management and reporting (for funding) • Understand **behavioural drivers, not just occurrence** of technology adoption to increase effectiveness of measures • Highlight **trade-offs** of policy goals with other needs of the society (e.g., food - energy security)
Economic • Improving **energy efficiency** of farms • Accounting for energy sources: Share of **direct and indirect energy costs** in total cost • Ensure efficient **allocation of public money** (investments, funding) • Measure the impacts of policies **on economic performance and wellbeing** of farming enterprise
Environmental • Shed light on **synergies and trade-offs** from multiple policy areas: agricultural and energy policy (food-bioenergy) • Monitoring **efficiency of agricultural inputs** and development of their **environmental impacts,** e.g. GHG • incl. accounting **externalities** of production and if policies shift environmental impacts elsewhere • incl. indicators to monitor impacts on soil carbon and the potential for **carbon offset** mechanisms
Governance • **Engagement of stakeholders** in decreasing fossil fuels dependence of the farming sector • Robust monitoring systems for **compliance** with regulatory frameworks and standards at various scales • Highlight impacts of national and EU regulations to compare effectiveness of different approaches • Publicly available/ **transparent** indicators with open data: to hold institutions **accountable** for performance
Mixed • Unveil **hidden trade-offs** of policies   ○ Understand trade-offs and synergies between social, economic and environmental aspects • Efficiency of resources use: highlight policy impact on various goals from different dimensions • Align data formats so they can be used to assess indicators in all dimensions efficiently

B) Evaluation of the indicators

In a second step and after presenting key results from the literature review, the participants provided feedback on a selection of key indicators for each dimension as identified during the literature review. The full indicator list was too as to be evaluated in-depth by the expert panel. The authors have therefore pre- selected the most relevant indicators for policy evaluation in the agri-energy-nexus. Those representative indicators (per category) served as basis for discussions with the aim to identify potential issues or important aspects that indicators should generally highlight.

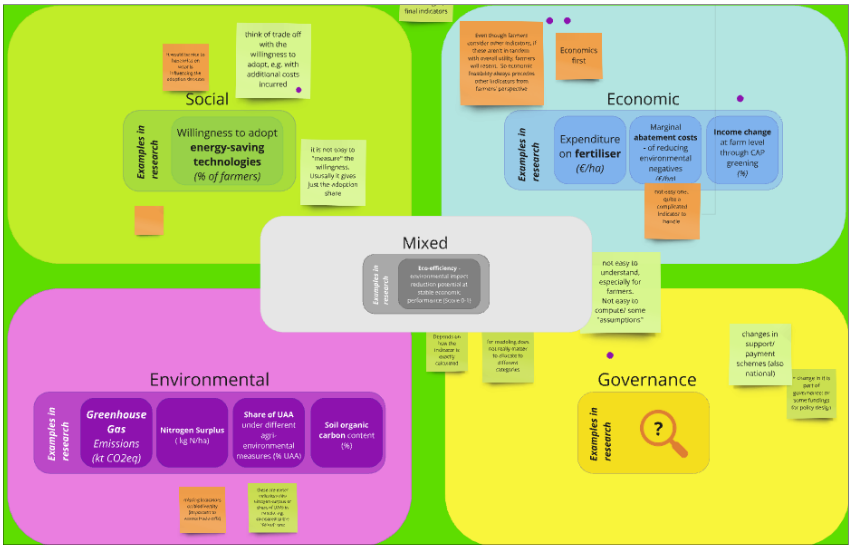

Figure 13 Miro board of the "indicators evaluation" exercise

Figure 13 illustrates how the Miro board looked like when implementing this activity with participants. The indicators were presented together with a proposed unit of measurement (metrics). Their relevance was then discussed and rated with the use of voting dots as well as post-it's for comments specifying choices. Table 5 provides a summary of the participants' comments on these indicators.

For each dimension we proposed a set of example indicators from the literature review representing the main sub-types of indicators. Participants could reflect on the example indicators based on the first discussion on the characteristics of "good" policy evaluation indicators.

It became immediately clear, that the more specific the indicators were, the more likely they would trigger discussion. Dependent on backgrounds and interests, stakeholders deemed an indicator more or less relevant. The dynamics reflected and reaffirmed the general difficulty to propose a consistent and widely applicable (or acceptable) set of policy indicators covering any purpose and that may be applied not only across different dimensions, but also across various scales and geographical areas. The fine line between feasibility and usefulness of indicators was at the core of many discussions: For example, mixed indicators such as eco-efficiency were considered critical to reflect interlinkages between dimensions. At the same time, however, they were evaluated as being highly complex, hard to measure and – thus – of limited practical utility for some stakeholders (like farmers). Along the same lines, the economic indicator for marginal abatement costs was considered interesting, yet quite complex to be modelled.

Table 5: Feedback on selected policy indicators from the external stakeholder workshop.

<table>
<tr><th>Indicator</th><th>Review</th></tr>
<tr><td colspan="2">Social</td></tr>
<tr><td>Willingness to adopt energy-saving technologies
(% of farmers)</td><td>• Interesting indicator but difficult to measure
○ Depends on several drivers
○ Gives idea about actual implementation, not potential one</td></tr>
<tr><td colspan="2">Economic</td></tr>
<tr><td>Expenditure on fertiliser
(€ ha^{-1})</td><td>• Particularly interesting if measured for different farming systems</td></tr>
<tr><td>Marginal abatement costs - of reducing environmental negatives (€/ha)</td><td>• Important, but complex indicator</td></tr>
<tr><td>Income change at farm level through CAP greening (%)</td><td>N/A</td></tr>
<tr><td colspan="2"><u>General consideration:</u> From farmer’s perspective, economics is priority. Other indicators need to be aligned (think of trad-offs) with overall utility for farmers not to resist.</td></tr>
<tr><td colspan="2">Environmental</td></tr>
<tr><td>Greenhouse Gas Emissions (kt CO_{2eq})</td><td rowspan="2">• Aligns with environmental goals and is tightly linked to energy use</td></tr>
<tr><td>Nitrogen Surplus
(kg N ha^{-1})</td></tr>
<tr><td>Share of UAA under different agri-environmental measures (% UAA)</td><td>N/A</td></tr>
<tr><td>Soil organic carbon content (%)</td><td>• Site specific: Change under specific policies interesting, Measurement difficult & uncertain.</td></tr>
<tr><td colspan="2"><u>General considerations":</u>
• Compared e.g. to “Mixed” indicators, easier to handle, like nitrogen surplus or share of UAA
• Many agri-environmental measures no specific energy target (rather fertilisation practices
• Missing indicators on biodiversity (important to assess trade-offs)</td></tr>
<tr><td colspan="2">Governance (no indicators available)</td></tr>
<tr><td colspan="2"><u>General considerations:</u>
• Time and costs of administrative process should be considered
• Changes in support / payment schemes, incl. at national level, more proactively accounted for</td></tr>
<tr><td colspan="2">Mixed</td></tr>
<tr><td>Eco-efficiency – environmental impact reduction potential at stable economic performance (Score 0-1)</td><td>Score (0 to 1) challenging to interpret considering “hidden” information. Outstanding indicator combining social, environmental, and economic factors.</td></tr>
<tr><td colspan="2"><u>General considerations</u>:
• Difficult to understand, particularly for farmers
• Challenging to calculate due to certain "hidden" assumptions</td></tr>
</table>

Environmental indicators – that were also most represented and elaborated already in literature – received comparably little critique and showed a solid ground of utility including for practical purposes to track policy impacts. However, it was highlighted that numerous are difficult to apply universally or would require more accuracy in data to be effective (esp. GHG or nitrogen surplus). Soil organic carbon content, crucial for assessing long-term soil health, is highly site-specific and challenging to evaluate across farming systems. The share of utilized agricultural area (UAA) under agri-environmental measures could highlight sustainable practices, though data availability is limited. Stakeholders also found that some relevant topics were underrepresented. For example, no indicators on biodiversity impacts of policies was presented, which was seen as essential to understand possible trade-offs of interventions. Similarly, it was noted that agricultural policies are not really aligned with more specific energy-relevant policies. A discussion that arose already in the policy analysis of the previous deliverable 1.1.

A core topic that was debated on the economic dimension is the impact of policies on farm's economic performance and farmer's wellbeing. Fertiliser expenditure per hectare was a concrete indicator that offers insights into actual costs of one of the most important fossil-energy based inputs. It was stressed that farmers would always prefer options that would not affect their income or business negatively, even if they might agree with the general objectives of policy interventions. Indicators measuring the impact of policies on the economic performance of farms were noted as highly critical; most notably that of marginal abatement cost related to expenses of reducing environmental harm. While being a valuable indicator it was also seen as complex and difficult to interpret. The discussions evoked general concerns about fair sharing of costs between farmers and society.

Social indicators, such as farmers' willingness to adopt energy-saving technologies, show interest but don't always translate into action, as many influencing factors are overlooked. A concrete aspect, or better limitation, mentioned when reviewing the willingness to adopt new technologies, was benchmarking. The existing indicators measuring actual achievements would become more informative if potential achievements through new policies were known *a priori* under ideal circumstances. In practical terms, however, such indicator would have to draw on numerous assumptions, which may be disputed.

Lastly, governance indicators were broadly absent in the literature review while the discussions were rather generic on the dimension as such. Participants in the workshop stressed, for instance, their favour for an indicator that could assess administrative burden (and thus discontent) imposed by policies on institutions and beneficiaries (e.g., farmers). This was particularly interesting for developing new rules or processes, e.g. regarding access for farmers to new payment schemes.

There was a particularly high interest in discussing mixed indicators that combine economic, environmental, and social factors. It was highlighted multiple times during the workshop that economic concerns frequently outweigh environmental and social priorities or concerns in both research and practice. Eco-efficiency as an indicator was deemed outstanding as it principally allowed outbalancing sustainability considerations with aspects of economic performance. However, hidden assumptions made it hard for farmers (and policy makers) to interpret and apply. The discussions did not go as far to further elaborate on possible bias in many approaches to prioritise economic over other aspects of sustainability (social, environmental, economic and governance process).

4. Discussion & Conclusion

The overall objective of the project AgEnRes is to contribute to fossil energy independence and resilience of the farming sector against energy price volatility. Work Package 1 (WP1) provides the shared and empirically substantiated analytical framework by reviewing current analytical approaches in research, policy and practice to measuring energy use and efficiency in EU agriculture. This deliverable serves the objective to provide a first stock-take of indicators in science and policy regarding their utility for the AgEnRes project aimed at reducing fossil fuel and fertilisers' dependence and enhancing resilience within European agriculture.

Both, the CAP (result indicators) and academic literature were reviewed regarding relevant indicators to measure and therefore evaluate policies supporting (or not) *energy dependency, energy-saving technologies* as well as the *adoption of* corresponding *innovations.* Indicators from both contexts where discussed with experts and stakeholders regarding their fitting with data and assessment requirements in the AgEnRes project (esp. models) as well as with political practice. Key principles and requirements for policy evaluation were elaborated on across core sustainability dimensions (environmental, social, economic, and governance) at the agri-energy nexus. On this basis, key gaps in research and practice were identified for (better) assessing the transition to a low-carbon, energy-resilient approach to agriculture.

AgEnRes: Advancing Policy Indicators for Energy Resilience in European Agriculture

As a first step, the study examined and identified pertaining gaps in the existing policy indicators under the Common Agricultural Policy (CAP) concerning energy use and related efficiency within farming practices as approached in the AgEnRes project. Although numerous of the existing policy result indicators are principally directly relevant (like renewable energy or climate innovations, or sustainable nutrient management) the metrics (e.g. number of farms) are typically not tailored to the specificities at the agri-energy nexus and the objective of fossil energy independence or resilience. Considering, the high political relevance of the matter in policy programmes (as highlighted in D1.1) there is a high political value in developing and applying energy-dependence sensitive indicators to better assess whether or not existing policies contribute to addressing energy dependence at the farm level in line with overall EU sustainability and climate resilience objectives.

Our co-creative analysis with key actors from policy and practice provides first grounds for developing actionable strategies for refining existing policy indicators, including for tracking progress of CAP to better capture aspects of sustainability and energy resilience in European agriculture. In concrete, existing CAP indicators that are indirectly linked to energy dependence (e.g. soil health) may be expanded further in their utility by employing data that explicates:

- Specific energy saving technology
- Knowledge or management approach applied to achieve the innovation or practical change
- Exact costs that are incurred by the intervention or innovation on the farm
- Area/UAA instead of number of farms

A pertaining gap in CAP indicators is the governance function. Through transparency, indicators may serve and increase the democratic quality of policy measures more generally, including by achieving higher levels of accountability through sharing openly what public money is spent for exactly. Already today options exist to develop simple but effective indicators to capture and track "good" governance performance of CAP or other measures based on metrics that offer insights into not only the types of concrete energy saving measures, knowledge or technologies and corresponding costs or energy load incurred or decreased through the specific policies. Indicators like nitrogen use efficiency, expenditure on fertiliser /energy, or eco-efficiency provide interested stakeholders with a foundation for assessing policies regarding their (environmental, economic or social) goal attainment and governance efficiency. A general data gap persists, however, concerning benchmarking existing policies and practices with 'potential better alternatives' (including better policy approaches to fostering innovations).

AgEnRes: Advancing Policy Indicators for Energy Resilience in Research

As a *second step*, the study elaborated on indicators used in research for measuring fossil energy dependence and resilience in the broadest sense.

The list of indicators retrieved from literature and presented in this report aimed, on one hand, at filling the identified gaps in the current CAP indicators at the agri-energy nexus. On the other hand, we looked specifically for indicators that would fit the research objectives in this project as to benefit and guide subsequent indicator selection procedure in other WPs. The overview is quite comprehensive and highlights current focus areas in the academic work. It became evident that environmental aspects of climate change or nutrient management and pollution were of core interest when addressing the agricultural sector. This corresponds also to the findings from Konefal et al. (2023), who found an imbalance in the distribution of indicators between different dimensions when reviewing an array of sustainability tools.

In the energy context, rather simple and widely used environmental indicators concerning nitrogen balance or nutrient use efficiency provide an indication on overuse or inefficient use of these energy-heavy resources (Oenema, 2015). In practical terms, optimising their use contributes to fossil energy independence. Paying heed to the agri-energy nexus more thoroughly, indicators need to focus more specifically on the exact source of nutrients to trace their potential fossil energy source and/or reliance on imports. Similarly, climate related indicators in the category "emissions" are greatly tied to energy consumption. However, most indicators do not focus on the share of fossil or renewable energy sources that hold responsible for these emissions deriving from field emissions, methane as well as diesel use or renewable energy. Targeted decision making relies on more nuanced information.

Economic indicators in literature were broadly relevant to this project's objectives. Expenditure on energy and fertilisers in combination with a total farm income, for instance, provide a thorough indication of the dependency on (fossil) energy inputs, even more so, where production efficiency is assessed (e.g., energy costs per unit of product sold). However, although specified in the search query, only one indicator specifies risk attitudes of farmers once, although a central aspect from the AgEnRes perspective. Considering the implications of fossil fuel price fluctuations for the resilience of a business in the agricultural sector, decisions under risk deserve more attention in theory and political practice, including regarding behavioural dynamics behind innovation.

Against this backdrop, the sole social indicator identified in this review focused on the current adoption rate of "innovations" by farmers mainly, while not allowing to explore the potential for adoption or factors behind actors' willingness to adopt, which are of higher interest at the agri-energy nexus. Such considerations seem currently broadly overlooked in the academic studies, in line with the gaps in the current policy landscape.

As a special case, mixed indicators may bridge the seemingly opposing categories of economics and environment. By capturing characteristics from both dimensions such indicators provide valuable insights into often hidden trade-offs and synergies that policy interventions might bring at the interface of different policy areas. This integrative trait was appreciated by experts in the workshop. Generally, more emphasis may be put on indicators that are able to grasp wider, systemic and complex impacts of policies.

Lastly, specific governance indicators were absent in the literature despite the general calls in science and policy for assessing the quality of governance (Kaufmann et al., 2010). The experts in the workshop also stressed the need for indicators assessing the effectiveness of public spending as well as for tools that ensure transparency in policy and that political actors may be held accountable for the (non)achievement of the set goals.

In synthesis, bringing all the findings together it may be concluded, that energy dependence of agriculture is not a core aspect of current interest when designing indicators to assess sustainability in agriculture, neither in policy, nor in academic discussion. Zhang et al. (2021), for instance, created a global sustainability matrix for agriculture. However, their literature review and expert panel did not include specific indicators on energy dependency. In addition, a large review of agricultural sustainability standards for cropping systems identified an overarching focus on environmental topics compared to other sustainability dimensions (Konefal et al., 2023). Within the environmental dimension, energy was less targeted than other categories such as GHG emissions or nutrient management. Overall a misalignment between distinct sustainability sub-topics identified by Scown et al. (2019) suggests a pertaining need to better collaborate across disciplines to create coherent and useful indicators across and between (mixed) all dimensions.

Likewise, the pertaining gap in suitable policy indicators at the agri-energy nexus may mirror the missing focus on energy dependence in EU agricultural policies as such. None of the ambitious goals of the current CAP targets energy dependency directly (Matthews, 2021). Also the complete lack of governance indicators comes partially as a surprise when considering that the SAFA tool and guidelines (FAO, 2014) are often referred to as a reference for the development of new tools and they cover governance aspects.

Furthermore, some core areas of interest to this project are underrepresented in the current long-list of indicators, namely the assessment of price risk mitigation for farmers through policies and the adoption potential of measures (innovations) by farmers as proposed in regulatory frameworks. Price volatility is included as a key economic indicator to assess global performance of agriculture in Zhang et al. (2021), but limited to the volatility of the sold crops, while fossil fuel price volatility is not directly addressed. In particular, at farm level we partly lack still data on specific GHG emission. While data is available for nitrogen or phosphorous use and even for expenditure on energy use available, these metrics cannot be allocated to specific activities or energy saving technology as a basis for changing practice, or developing and assessing supportive policies. It will only follow in work package 2 of the AgEnRes project that the data will be further refined.

Advancing Policy Indicators for Energy Resilience at the science policy interface

Achieving energy independence in agriculture is a subject of highly strategic importance for the sustainable development of the sector. Nonetheless, key challenges and gaps pertain regarding suitable indicators and metrics (and data) to assess existing and future policies at the agri-energy nexus towards this goal. Apart from more technical questions in relation to the right levels of analysis, specificities or suitable metrics to reflect innovation, behavioural and social aspects or governance, a major challenge remains with selecting indicators that work in both realms: research *and* policy.

Past experience and analytical work suggest that for scientific information (including on indicators) to work in and for the policy context, it needs to strike a balance across three core principles of effective knowledge transfer: *credibility* (scientific rigor), *saliency* (practical relevance) and political *legitimacy* (Cash et al., 2002). Considering where current agricultural policies stand regarding integrating fossil energy independence or resilience, it may seem less as a surprise that indicators specific to the agri-energy nexus are hardly applied in policy evaluation practice or that the research on those policies offers just a few more options and often with a certain imbalance towards indicators that already work for evaluating other objectives and subject areas (e.g. climate, nutrients or economic evaluations). While work in AgEnRes is still ongoing and needs to further specify novel indicators for concrete sub-questions (e.g. technology adoption, risk taking, governance etc.), the corresponding metrics deemed useful for modelling need to still prove their utility and acceptability in the policy arena.

For the work in task 1.3 discussion with stakeholders were key for better understanding the concrete needs in policy and practice as to what useful or acceptable indicators offer on a principle level. In subsequent work packages, AgEnRes will have to engage with stakeholders even further to explore how indicators and metrics can be aligned with the realities of policy making, or even inform policy development, accordingly. A major challenge remains not only with the fact that indicators may have to work in different countries or contexts, but also that assessing policy impact against targets is 'highly political' and may be politically unfavourable despite general agreement on values like transparency or traceability of governance. The reasons behind lacking or unsuitable variables, data or metrics are not always 'just' technical matters of facts, but may as well reflect what is wanted or unwanted (Weiss, 1993)

The AgEnRes project work at the agri-energy nexus is a telling example of challenges of knowledge exchange at the science-policy interface. While CAP indicators were not deemed very useful for the scientific work in the project, because of lacking precision and goal orientation (focused at energy independence), the existing scientific indicators do not seem to represent the agri-energy nexus well either. Where they did, they still often did not convey information in a way that was seen practicable or desirable in a policy context. The indicators partly require too much data, have too much or too little granularity and so on. However, the subject of resilience of the agricultural sector against fossil energy price volatility is too serious an issue in science and policy as to dismiss further legitimate efforts to develop indicators and metrics for policy evaluation at the agri-energy nexus.

In this regard this report offers a first principal guidance for navigating the rather unknown waters of indicators at the agri-energy nexus. The main considerations and findings for AgEnRes derived from policy and literature review and stakeholder exchange may be summarised as displayed in

Table 6**.**

Table 6 Overview of the core interests of AgEnRes modelling and matching state-of-the-art indicators. Considerations derived from this report can guide the development and selection of relevant indicators for upcoming tasks.

CAP result indicators: Indicator/metrics used	CAP result indicators: Review result	AgEnRes data needs	Indicators in literature: Review result	Indicators in literature: Key Indicator/metrics used	Open challenges & options
▪ **R22: % farms** supported in nutrient management ▪ **R16: % farms** supported in climate change investments	➢ Indicators too unspecific ➢ esp. on specific innovations	Assess *energy dependency*	➢ Environ. / economic often unspecific ➢ Economic indicators most suitable to reflect risk to business	▪ Fertiliser **costs: € /ha** ▪ Energy **costs: € /ha**	➢ More comprehensive indicators needed: **energy focus** ➢ Economic & environmental indicators **over-represented** ➢ **Governance** or **social aspects** of technologies (impacts) unclear ➢ **Easy-to-communicate** indicators for all stakeholders needed ➢ **Innovations**: Greatest potential for 'novel' indicators ➢ Lack of **transparency** /accountability indicators ➢ **Adoption** potential of innovations lacking
▪ **R22: % farms** supported in nutrient management ▪ **R15: MW** installed RE supported ▪ **R9: % farms** supported in farm modernization ▪ **R19: ha** under beneficial soil management ▪ **R20: % UAA** under ammonia emissions reduction commitment	➢ Topic-wise numerous indicators suitable ➢ Current metrics not reflective of performance ➢ Mostly silent on technology outcome	Assess *energy-saving technologies*	➢ Economic/ environ. indicators on technology impact available ➢ Need clear quantitative indication of improvements ➢ Need careful use of site-specific indicators (soil) ➢ Suitable mixed indicators (trade-offs), but complex	▪ fossil energy-GHG emissions : **CO_{2eq}**/ha ▪ NUE: % ▪ N-balance: kg N/ ha ▪ Soil organic **carbon** change: **%** ▪ Marginal abatement **cost: €/ha** ▪ Eco-efficiency: 1-0 score	
▪ **R29: % UAA** supported for organic farming ▪ **R5: % farms** supported in risk management tools	➢ Shows *how many profit* ➢ Lacks specificity on share of used potential	Assess *innovation adoption potential*	➢ Literature lacks focus on this goal, esp. risk/behavior related ➢ Social indicators hard to measure & need accuracy	▪ Area under organic cultivation (ha UAA) ▪ Willingness to adopt energy saving technologies	

[1]Colour codes for indicator target categories: red – environmental, blue – economic, green – social, grey – mixed.

On a principle note science and policy may differ in terms of their approaches to and requirements for 'good' policy indicators, However, there is also a considerable shared ground when looking at the overlap of research and policy concerning key knowledge interests: namely to assess how and where agriculture is dependent, which technologies may help saving energy to what degree and what needs to change on farms to overcome dependency.

Indeed, data that allow to identify exactly what practices at farm level support achieving energy efficiency and thereby contribute to sustainability and resilience of the sector have a high value for both audiences. Gaps persist especially with mixed indicators (considering trade-offs, e.g. with biodiversity), but also regarding behavioural indicators (understanding better adoption and taking risks) that make model predictions more accurate and in consequence also more salient to political decision making and planning. Governance and social indicators although still very rare score high on fairness or accountability principles in knowledge production and should be in the 'self-interest' of democratic policy-making.

Still, the described limitations of CAP result indicators for use in AgEnRes may not be misinterpreted as a general lack of utility for policy. Rather their mismatch with analytical requirements in AgEnRes reaffirm the insights from Deliverable 1.1 that existing policies and support measures – including their approaches to monitoring – do not reflect key objectives at the agri-energy nexus with regard to achieving fossil energy independence. While the indicators are generally relevant, they need considerable adjustment and refinement to improve precision and adaptability for better assessments of sustainable agricultural practices that are able to reflect progress towards independence from fossil-energy inputs and price volatility.

In this regard, the AgEnRes project provides a relevant analytical foundation for developing energy-specific agricultural policies and indicators for Europe. By addressing pertaining gaps in current frameworks and proposing actionable solutions, this report provides a first stock-take of more effective monitoring of fossil fuel reliance, energy efficiency, and renewable energy adoption to be further specified in subsequent work packages

Overall, the EU is politically committed to moving ahead on a low-carbon trajectory, however in political (D1.1) and practical reality (D1.2) countries still lack behind their targets at the agri-energy nexus. The EU agriculture remains broadly dependent upon sources of (fossil) energy. To capitalise on the relatively high potential for being a major producer of renewable energy and for implementing agricultural innovation, it will be critical that policies are better integrating different objectives at the agri-energy nexus. Developing robust and relevant energy-focused indicators are an important ingredient for agricultural policies to better integrate sustainability (e.g. climate) goals with objectives of increasing the resilience of the sector against energy price volatility. The AgEnRes framework offers a first scientifically grounded foundation for evaluating and improving policies at the agri-energy nexus ensuring the long-term success of Europe's efforts to build a sustainable and energy-resilient agricultural sector.

On this basis energy-focused indicators may be developed to be integrated into the CAP framework to more effectively monitor energy efficiency, track renewable energy adoption, or assess the effectiveness and efficiency of policies aimed at reducing fossil fuel dependence. By refining and expanding these indicators, the EU can better align agricultural policies with its climate and sustainability goals. Metrics reflective of the peculiarities at the agri-energy nexus will enable policymakers, farmers, and researchers to more comprehensively track progress, adapt strategies, and support the transition to a low-carbon, energy-resilient agricultural sector.

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Annex

A1. Long list of CAP indicators

Table 7 Long list of CAP indicators deemed relevant for AgEnRes as selected during an internal review process and then discussed with partners during the internal workshop

Indicator	Description	Unit	Methodology	Usefulness check Yes (+)	no (-)	maybe (/)
R.1 Enhancing performance through **knowledge and innovation** (indirect)	To quantify the coverage of interventions supporting the provision of knowledge, innovation-generation, and exchange for agriculture and rural areas to enhance sustainable economic, social, environmental, climate, and resource efficiency performance.	Number of persons	Number of persons benefitting from relevant paid support.		-	//
R.2 Linking **advice and knowledge** systems (indirect)	To quantify the support provided to advisors from relevant CAP interventions effectively contributing to integration within the Agricultural Knowledge and Innovation Systems (AKIS).	Number of advisors	Number of advisors supported by interventions related to advisors' integration into the AKIS.			//
R.5 **Risk Management**	To quantify the coverage of risk management tools.	%	Number of farms benefitting from relevant support / Total number of farms	++	-	
R.8 Targeting farms in specific sectors (direct)**	This indicator reflects the extent of the support provided in sectors undergoing difficulties, in terms of the share of farms. Such support aims to improve competitiveness, sustainability, or quality.	%	Number of beneficiaries of coupled income support / Total number of farms.	++	-	
R.9 **Farm modernization** (direct)	To quantify the coverage of interventions providing support for farm modernization to restructure and modernize, including to improve resource efficiency.	%	Number of beneficiaries receiving relevant support / Total beneficiaries.	+++		
R.12 **Adaptation to climate change**	To quantify the coverage of commitments to improve adaptation to climate change in agricultural practices.	%	Number of hectares / Total Utilised Agricultural Area (UAA).		--	/

R.14 **Carbon storage** in soils and biomass (indirect)	To quantify the coverage of interventions supporting carbon storage and sequestration in agriculture and forestry.	%	Number of hectares under relevant management practices / Total UAA.	+		//
R.15 **Renewable energy** from agriculture, forestry, and other renewable sources (direct)	Supported investments in renewable energy production capacity, including bio-based (in MW).	MW	Total installed capacity of renewable energy production supported by the CAP.	+++		
R.16 **Investments** related to **climate** (direct)	Share of farms benefitting from CAP investment support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterials.	%	Number of farms receiving relevant investment support / Total number of farms.	+		//
R.17 **Afforested land** (indirect)	Area supported for afforestation, agroforestry, and restoration, including breakdowns.	Hectares	Total area supported for afforestation, agroforestry, and restoration.	+	--	/
R.19 Improving and protecting **soils** (indirect)	Share of utilised agricultural area (UAA) under supported commitments beneficial for soil management to improve soil quality and biota (such as reducing tillage, soil cover with crops, crop rotation included with leguminous crops).	%	Number of hectares under beneficial soil management practices / Total UAA.	++++		
R.20 Improving **air quality** (indirect)	Share of utilised agricultural area (UAA) under supported commitments to reduce ammonia emission.	%	Number of hectares under commitments to reduce ammonia emission / Total UAA.	++		//
R.21 Protecting **water quality** (indirect)	Share of utilised agricultural area (UAA) under supported commitments for the quality of water bodies.	%	Number of hectares under commitments to protect water quality / Total UAA.			//
R.22 Sustainable **nutrient management** (direct)	Share of utilised agricultural area (UAA) under supported commitments related to improved nutrient management.	%	Number of hectares under improved nutrient management practices / Total UAA.	++		/

R.24 Sustainable and reduced use of **pesticides** (indirect)	Share of utilised agricultural area (UAA) under supported specific commitments which lead to a sustainable use of pesticides in order to reduce risks and impacts of pesticides such as pesticides leakage.	%	Number of hectares under sustainable use of pesticides / Total UAA.			///
R.28 Environmental or climate-related performance through **knowledge and innovation** (indirect)	To quantify the coverage of interventions supporting the provision of knowledge, innovation-generation, and exchange related to environmental or climate-related performance.	Number of persons	Number of persons benefitting from relevant paid support			///
R.29 Development of **organic agriculture** (indirect)	Share of utilised agricultural area (UAA) supported by the CAP for organic farming, with a split between maintenance and conversion.	%	This indicator is composed of 3 specific indicators: 1. Share of UAA supported by the CAP for organic farming. 2. Share of UAA supported by the CAP for organic farming maintenance. 3. Share of UAA supported by the CAP for organic farming conversion.	++		//
R.38 **LEADER** coverage (indirect)	To quantify the share of the rural population covered by LEADER interventions.	%	Rural population covered by Local Action Groups (LAGs) funded through LEADER over the programming period / Total rural population.	+	--	

A2. Outline of internal workshop reviewing the CAP indicators

The workshop provided a platform for participants to reflect on the relevance and applicability of CAP result indicators for AgEnRes. It served as exchange for concretising expectations towards indicators in relation to the broader as well as specific project objectives setting the stage for subsequent tasks.

Agenda item 1: Rationale and objectives of the workshop

The workshop began with a presentation by the organizers with the following outline:

a. Introduction:
   - Identify the relevance and feasibility of CAP Result Indicators in the AgEnRes context.
   - Pinpoint data gaps in the indicators for AgEnRes

b. Expected outcomes:
   - Contribute to knowledge on relevant indicators for energy use and dependency policy evaluation
   - Prepare participants for future policy monitoring and evaluation studies

c. Feedback request:
   - Gather participant comments
   - Gain approval for the workshop design

Agenda Item 2: Recap of previous work

The organisers presented key elements of the progress made in WP1 and Task 1.3, including reviews of EU and national policies on energy use and dependency with a highlight on elements of particular importance to work in task 1.3: e.g. CAP result indicators identified from the CAP framework (D1.1) and clarified energy use sources and boundaries defined in Task 1.2.

Agenda Item 3: CAP results indicators at the agriculture-energy nexus

Participants evaluated CAP result indicators in break-out groups along two lines:

a. Reflection on Relevance and Feasibility:
   - *Relevance*: How well do the indicators capture progress toward energy independence and resilience in European agriculture?
   - *Feasibility*: Can the indicators be integrated into AgEnRes work and modelling?

b. Voting and Justification: Participants rated indicators against these criteria and provided justifications using post-its.

Agenda Item 4: Specifying Data & Indicator Gaps

Break-out group discussions on:

a. Shortcomings of the CAP result indicators.

b. Missing indicators or lacking data needed for improved evaluation.

Agenda Item 5: Indicator Literature Review Overview

The methodology for the literature review on policy monitoring and evaluation indicators was presented, covering:

1. Selection Criteria and Query
2. Pre-Screening using ASReview
3. In-depth Screening

Agenda Item 6: Summary and feedback

The workshop concluded with:

a. A summary of outcomes.

b. Participant feedback and additional points.

c. A briefing on next steps.

A3. Outline of external workshop reviewing indicators and defining goals

Agenda item 1: Rationale and objectives of the workshop

The Workshop started with an introductory presentation by the organizers explicating the following aspects:

a. Purpose for participants:
  - Identify practice-ready indicators for policy evaluation;
  - Discuss the attributes of "good" indicators for policy evaluation.

b. Expected outcomes for participants:
  - Contribute knowledge on relevant indicators;
  - Enhance preparation for future policy monitoring and evaluation efforts.

c. Participant feedback:
  - Solicit comments and suggestions;
  - Confirm participant agreement on the workshop design.

Agenda item 2: Recap of Previous Work – Policy and Innovation Reviews

The idea was to familiarise participants, especially those not familiar with AgEnRes with key objectives and the work already completed in WP1, specifically prior Tasks 1.1 and 1.2. The presentation summarized policy reviews conducted at EU and national levels in Europe, alongside relevant innovations or practices aimed at reducing energy use and dependency.

Agenda item 3: Goals for Policy Indicators at the Agriculture-Energy Nexus

On this ground participants worked in breakout groups to identify and rate the importance of specific goals to achieve through policy indicators ordered across four distinct dimensions (as identified in literature) —Social, Economic, Environmental, and Governance. The process included:

a. Assigning goals deemed important to each dimension;
b. Voting on favourite goals using up to six "IMPORTANT" dots, with free allocation across goals. Justifications were provided on post-it notes.

Agenda item 4: Review of Indicator Literature

After participants had a clear understanding of their expectations towards policy indicators, the team presented the methodology and key findings of the literature review on indicators for policy monitoring and evaluation that concerned energy use and dependency in Europe. On the basis of the discussions in step 3, participants were expected to be better equipped to evaluate the relevance and effectiveness of the proposed indicators from literature.

Agenda item 5: Indicator Evaluation

Participants evaluated the proposed indicators for their quality and relevance through breakout group discussions:

a. Participants evaluated the proposed indicators for their quality and relevance through breakout group discussions;
b. Voting on favourite indicators using up to six "LIKE" dots, with justifications noted on post-its.

Agenda item 6: Summary and Feedback

The workshop concluded with a summary of outcomes, followed by participant reactions.
Participants were invited to add further comments or general feedback.

Figure 14 Screenshot from the AgEnRes website to register to the external workshop

A4. List of included studies in the literature review

Table 8 Final list of studies used to extract indicators after pre- and full-text screening in the literature review

Study ID	Authors	Date	Link/DOI
5	['Syp, A', 'Osuch, D', 'Gebka, A']	2023	Assessment of environmental performance on farms using FADN: a case study of the Region of Mazowsze and Podlasie, Poland (journalssystem.com)
6	['Baráth, L', 'Bakucs, Z', 'Benedek, Z', 'Ferto, I', 'Nagy, Z', 'Vígh, E', 'Debrenti, E', 'Fogarasi, J']	2024	https://doi.org/10.1016/j.scitotenv.2023.167518
9	['Uehleke, R', 'Petrick, M', 'Hüttel, S']	2022	https://doi.org/10.1016/j.landusepol.2021.105950
10	['Köster, T', 'Vask, K', 'Koorberg, P', 'Selge, I', 'Viik, E']	2009	ISSN1822-3230_2009_V_4_1.PG_219-224.pdf (vdu.lt)
14	['West, B', 'Jones, DL', 'Robinson, EL', 'Marrs, RH', 'Smart, SM']	2023	Model-based assessment of the impact of agri-environment scheme options and short-term climate change on plant biodiversity in temperate grasslands - West - 2023 - Ecological Solutions and Evidence - Wiley Online Library
19	['Himics, M', 'Fellmann, T', 'Barreiro-Hurle, J']	2019	https://doi.org/10.1111/1477-9552.12339
20	['Tzemi, D', 'Mennig, P']	2022	https://doi.org/10.1016/j.jrurstud.2022.03.006
21	['Marconi, V', 'Raggi, M', 'Viaggi, D']	2015	https://doi.org/10.1016/j.ecolind.2015.02.037
25	['Mouratiadou, I', 'Russell, G', 'Topp, C', 'Louhichi, K', 'Moran, D']	2010	10.2166/wst.2010.216
29	['Slabe-Erker, R', 'Bartolj, T', 'Ogorevc, M', 'Kavas, D', 'Koman, K']	2017	https://doi.org/10.1016/j.ecolind.2016.09.048
32	['Gallego-Ayala, J', 'Gómez-Limón, JA']	2009	View of Analysis of policy instruments for control of nitrate pollution in irrigated agriculture in Castilla y León, Spain (csic.es)
35	['Soteriades, AD', 'Stott, AW', 'Moreau, S', 'Charroin, T', 'Blanchard, M', 'Liu, JY', 'Faverdin, P']	2016	10.1371/journal.pone.0166445
42	['Cortignani, R', 'Dono, G']	2019	https://doi.org/10.1016/j.scitotenv.2018.07.443
43	['Semaan, J', 'Flichman, G', 'Scardigno, A', 'Steduto, P']	2007	https://doi.org/10.1016/j.agsy.2006.10.003
44	['Dokic, D', 'Matkovski, B', 'Jeremic, M', 'Duric, I']	2022	Land | Free Full-Text | Land Productivity and Agri-Environmental Indicators: A Case Study of Western Balkans (mdpi.com)
51	['Sieber, S', 'Amjath-Babu, TS', 'Jansson, T', 'Müller, K', 'Tscherning, K', 'Graef, F', 'Pohle, D', 'Helming, K', 'Rudloff, B', 'Saravia-Matus, BS', 'Paloma, SGY']	2013	https://doi.org/10.1016/j.landusepol.2013.01.002

54	['Ghisellini, P', 'Ncube, A', 'Rotolo, G', 'Vassillo, C', 'Kaiser, S', 'Passaro, R', 'Ulgiati, S']	2023	https://doi.org/10.3390/en16041671
56	['Förster, M', 'Helms, Y', 'Herberg, A', 'Köppen, A', 'Kunzmann, K', 'Radtke, D', 'Ross, L', 'Itzerott, S']	2008	A Site-Related Suitability Analysis for the Production of Biomass as a Contribution to Sustainable Regional Land-Use | Environmental Management (springer.com)
57	['Giupponi, C', 'Rosato, P']	1999	https://doi.org/10.1016/S0273-1223(99)00045-1
61	['Poblete, CD', 'Valero, JSC', 'Garcia-Cortijo, MC']	2024	Environmental assymetry between the pillars of the CAP: the case of Spain | Environment, Development and Sustainability (springer.com)
65	['Paris, B', 'Kanaki, V', 'Koutsouris, A', 'Balafoutis, A. T', 'Papadakis, G']	2024	Full article: Farmers' needs, ideas and interests on the adoption of fossil energy free technologies and strategies in the EU (tandfonline.com)
66	['Viaggi, D', 'Raggi, M', 'Paloma, SGY']	2013	https://doi.org/10.1016/j.envsoft.2013.01.014
67	['Gadermaier F', 'Berner A', 'Fließbach A', 'Friedel JK, Mäder P']	2011	Impact of reduced tillage on soil organic carbon and nutrient budgets under organic farming | Renewable Agriculture and Food Systems | Cambridge Core
71	['Myszograj, S', 'Pluciennik-Koropczuk, E']	2022	Environmental Aspects of Sustainable Agriculture (ceer.com.pl)
72	['DONALDSON, AB', 'FLICHMAN, G', 'WEBSTER, JPG']	1995	https://doi.org/10.1016/0308-521X(94)00009-G
80	['Fanelli, RM']	2023	Agronomy | Free Full-Text | Assessing the Convergence of Farming Systems towards a Reduction of Greenhouse Gas Emissions in European Union Countries (mdpi.com)
81	['Marada, P', 'Krikava, L', 'Krikava, L', 'Kutlvasr, K', 'Sláma, P']	2012	Agroenvironmental management system - a technique for increasing the natural value of agroecosystems (repec.org)
88	['Boone, L', 'Dewulf, J', 'Ruysschaert, G', "D'Hose, T", 'Muylle, H', 'Roldán-Ruiz, I', 'Van Linden, V']	2020	https://doi.org/10.1016/j.jclepro.2019.119000
90	['Bojar, W', 'Zarski, W', 'Kusmierek-Tomaszewska, R', 'Zarski, J', 'Baranowski, P', 'Krzyszczak, J', 'Lamorski, K', 'Slawinski, C', 'Mattas, K', 'Staboulis, C', 'Natos, D', 'Koc, AA', 'Bayaner, A', 'Roldan, AO', 'Rivero, OP']	2023	Resources | Free Full-Text | A Comprehensive Approach to Assess the Impact of Agricultural Production Factors on Selected Ecosystem Services in Poland (mdpi.com)
93	['Syp, A', 'Osuch, D']	2018	Assessing Greenhouse Gas Emissions from Conventional Farms Based on the Farm Accountancy Data Network (pjoes.com)
111	['Duru, M', 'Bergez, JE', 'Delaby, L', 'Justes, E', 'Theau, JP', 'Viégas, J']	2007	https://doi.org/10.1016/j.jenvman.2005.12.014
113	['Myszograj, S', 'Pluciennik-Koropczuk, E']	2022	Assessment of agricultural sustainability in European Union countries: a group-based multivariate trajectory

			approach | AStA Advances in Statistical Analysis (springer.com)
124	['Puertas, R', 'Marti, L', 'Calafat, C']	2023	Agricultural and innovation policies aimed at mitigating climate change | Environmental Science and Pollution Research (springer.com)
129	['Spiegel, A', 'Britz, W', 'Djanibekov, U', 'Finger, R']	2018	https://doi.org/10.1016/j.biombioe.2018.01.003
140	['Toma, P', 'Miglietta, PP', 'Zurlini, G', 'Valente, D', 'Petrosillo, I']	2017	https://doi.org/10.1016/j.ecolind.2017.07.049
174	['Gocht, A', 'Ciaian, P', 'Bielza, M', 'Terres, JM', 'Röder, N', 'Himics, M', 'Salputra, G']	2017	EU-wide Economic and Environmental Impacts of CAP Greening with High Spatial and Farm-type Detail - Gocht - 2017 - Journal of Agricultural Economics - Wiley Online Library
176	['Quemada, M', 'Lassaletta, L', 'Jensen, LS', 'Godinot, O', 'Brentrup, F', 'Buckley, C', 'Foray, S', 'Hvid, SK', 'Oenema, J', 'Richards, KG', 'Oenema, O']	2020	https://doi.org/10.1016/j.agsy.2019.102689
177	['Acosta-Alba, I', 'Lopéz-Ridaura, S', 'van der Werf, HMG', 'Leterme, P', 'Corson, MS']	2012	https://doi.org/10.1016/j.jclepro.2011.11.061
182	['Biffi, S', 'Traldi, R', 'Crezee, B', 'Beckmann, M', 'Egli, L', 'Schmidt, DE', 'Motzer, N', 'Okumah, M', 'Seppelt, R', 'Slabbert, EL', 'Tiedeman, K', 'Wang, HL', 'Ziv, G']	2021	Aligning agri-environmental subsidies and environmental needs: a comparative analysis between the US and EU - IOPscience
201	['Follador, M', 'Leip, A', 'Orlandini, L']	2011	https://doi.org/10.1016/j.envpol.2011.01.025
204	['Gaudino, S', 'Reidsma, P', 'Kanellopoulos, A', 'Sacco, D', 'van Ittersum, MK']	2018	Agriculture | Free Full-Text | Integrated Assessment of the EU's Greening Reform and Feed Self-Sufficiency Scenarios on Dairy Farms in Piemonte, Italy (mdpi.com)
223	['Hutchings, NJ', 'Sorensen, P', 'Cordovil, CMDS', 'Leip, A', 'Amon, B']	2020	https://doi.org/10.1016/j.gfs.2020.100381
239	['Zafeiriou, E', 'Petridis, K', 'Karelakis, C', 'Arabatzis, G']	2016	https://doi.org/10.1016/j.enpol.2016.06.034
245	['Biagini, L', 'Severini, S']	2022	Sustainability | Free Full-Text | How Does the Farmer Strike a Balance between Income and Risk across Inputs? An Application in Italian Field Crop Farms (mdpi.com)
256	['Pérez-Soba, M.', 'Coderoni, S.', 'Helming, J.', 'Muller, M.', 'Sckokai, P.', 'Varacca, A.']	2021	D 1.2_Indicator framework for measuring the impact of policiesglobal drivers on IDM units in agriculture.pdf (mind-step.eu)